How Virtual Therapeutics
Will Revolutionize Medicine

VRx

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BASIC BOOKS
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Contents

To my wife and children, who make living
in real reality an ever-present joy.

BASIC
BOOKS

Author's Note

The following patients were interviewed for this book and graciously allowed their names to appear within their stories: Richard Breton, Danielle Collins, Harmon Clarke, Tom Norris, Robert Jester, and Erin Martucci. The names of other patients were changed and elements of their stories modified to preserve confidentiality.

I have made every effort to write a scientifically accurate book supported by hundreds of citations. However, there are thousands of additional studies that I could not include due to space restrictions. I selected studies that I believe will stand the test of time and relied on randomized controlled trials, when available, to support assertions in the text. Any factual errors in this book are my responsibility; please contact me should you find inaccuracies and I will seek to correct the record.

INTRODUCTION

A Leap of Faith

When virtual reality first took hold of me, I thought I was going to die. Walter Greenleaf, a leading virtual reality (VR) scientist from Stanford University, visited my lab at Cedars-Sinai Medical Center in Los Angeles in 2014 with a team of programmers to demonstrate their supercharged tech. They placed a headset over my eyes, and the world disappeared into blackness. It felt as though I were sitting in an unlit cavern awaiting some unwelcome surprise. Suddenly, a bright scene ignited into crisp reality, and I found myself standing outside on a shaky window-washing rig, slowly ascending the side of a fifty-story building. I heard creaking cables and the sound of a steady breeze. I felt the butterflies of anxiety and began swaying in rhythm with the teetering platform beneath my feet.

The rig stopped at the top of the building. I stood looking out upon a downtown cityscape, perched hundreds of feet in the air above a concrete sidewalk. It felt dangerous, even though I was standing in a familiar conference room. My heart was palpitating, nerves were firing, and tendons stiffening. A few seconds passed. I settled in long enough to register the beauty of the scene and note details, like the signage atop buildings, the glint of sunlight reflecting off windows, and traffic patterns in a far-off rotary.

Without warning, the rig's protective railing suddenly detached, plummeting end-over-end and crashing into the street far below. I nearly panicked. Some inner spirit took control of my limbs. I reached back in desperation for the "window" behind me

(which was a whiteboard on the conference room wall). I shut my eyes to escape and think. This would all be fine if I could only reason my way through it. My feet knew they were standing on carpet, but how could I get my brain to know this as well?

"Okay, now jump off the platform," said Greenleaf. "Just take one big step into the void."

Not a chance. There was no way I was going to leap off that building. It made no difference that I knew I was in a conference room. This virtual world had commandeered my brain. I was paralyzed with fear.

Reading about VR is like reading about space travel—you might imagine the effortless glide of floating in zero gravity, but until you are in space, well, you're not. Unless you have been inside virtual reality it's hard to imagine how powerful it is. So the next best way to experience it is to watch others try it. Here is one of my patients using VR while suffering from the severe pain of sickle cell anemia. Before taking this picture, he was doubled over from body aches despite taking powerful painkillers. At this moment, he is flying in a helicopter over fjords in Iceland. It is hard to tell that he's in pain.[i]

This book is about why he isn't in pain and what that means for how we treat some of our most pressing health threats.

Perhaps you think that VR is a gaming technology—a toy for pimply, pent-up teens to play first-person shooter games in their

parents' basement. You wouldn't be alone. Maybe you have a VR headset for a Sony PlayStation, or you know someone who uses Oculus or Samsung Gear VR to play games in fantasy worlds. Maybe you read *Ready Player One*, the Ernest Cline novel, or saw the movie version, where people become so obsessed with the virtual world that they neglect the real one. Maybe you think of VR as just another addictive screen. And then there's VR pornography... that's a whole other story.

People tend to think of VR only in terms of technology that has been brought to the consumer market. They think it's about wearing big goggles. Let me be clear: VR is not about goggles. Today's headsets will cede to tomorrow's VR eyeglasses or contact lenses that are digitally connected to a network of miniaturized body sensors. Future virtual worlds will stimulate not just our vision but all our senses, using smaller, more portable, and less expensive devices. We will be able to travel with VR wherever we go. VR will connect mind and body in a bid to support virtual biofeedback. Wearable activity monitors, heart rate monitors, electroencephalograms, and stress sensors will drive the VR experience in an ever-changing, personalized, immersive experience. These applications will improve the way virtual worlds are created. But they are not what VR really is.

Rather, VR is a way to deliberately and predictably modify how we feel and how we think. It's a platform that connects us to our heart, mind, and body. I mean that literally. VR can be used toward a variety of ends, but I am going to talk specifically about how VR can be used to help us heal in ways that other treatments cannot. As the technology advances, scientists are discovering just how effectively VR alters our perception of reality. We've found that it can manage pain, lower blood pressure, treat eating disorders, and combat anxiety. VR helps deliver babies and enables soldiers to cope with the mental scars of war. And in an unexpected way, VR is bringing the humanity back into healthcare. I will use the term "VR" throughout this book as shorthand for all of this. But when I use that term, understand that I am referring to the revolutionary new science of immersive therapeutics, not a headset. Calling it VR is just short and sweet.[ii]

VR is revolutionary because it compels us to think of patients differently than we doctors typically do. Doctors tend to think

about patients as broken machines. VR rejects this notion and makes the case that in medicine, people's subjective lives matter. Jaron Lanier, the noted computer scientist who originally coined the term "virtual reality," says it best:

> VR is the most humanistic approach to information. It suggests an inner-centered conception of life, and of computing, that is almost the opposite of what has become familiar to most people, and that inversion has vast implications.... Most technology reinforces the feeling that reality is just a sea of gadgets; your brain and your phone and the cloud computing service all merging into one superbrain.... VR is the technology that instead highlights the existence of your subjective experience. It proves you are real.[1]

There's a lot to unpack in Lanier's vision of humanistic VR. This book will tell you something about what that quote means, from the perspective of a physician who has used VR for years alongside traditional medical treatments. VR is not just for gamers anymore; it is a new type of medicine that not only has potential to heal but also can strengthen the bond between doctor and patient.

My own virtual leap revealed how VR can hijack the brain and create a sense of psychological *presence*. When VR scientists speak of presence, they mean that VR has a unique ability to convey a sense of just "being there," wherever *there* happens to be. It might be relaxing on a beach or soaring in a hang glider or swimming with dolphins or, in my case, tumbling off the side of a building. VR can even cause people to think and feel like another person altogether. In these pages, we'll see how VR enables people with depression to assume the body of Sigmund Freud and engage in self-counseling through his persona, allows patients with anorexia to experience life by way of a healthy avatar, and teleports people outside their own body so that they may gain new insights about the nature of dying. In all of these cases, if the VR is any good, the user feels transported to a new virtual environment and temporarily accepts it as reality. When used in the right way, at the right time, and with the right patient, these virtual journeys

can change mind and body for the better.

It turns out that our brains are designed to live in one reality at a time. Hard as I tried while standing atop that building, my brain could not occupy two worlds at once. It could not contemplate the vivid reality of imminent death while simultaneously accepting the bland reality of standing in a conference room. I was shockingly unable to separate real from virtual. That's the power of presence and, in a nutshell, the power of VR. All of its revolutionary potential tumbles out of its ability to compel a person's brain and body to react to a different reality.

This book also traces a personal journey of scientific discovery. As a traditional Western-trained physician, I had doubts that VR could ever become part of my medical practice. At first, the technology seemed more like a nifty optical illusion than a meaningful therapeutic. I wasn't sure how a headset built for gaming and entertainment could truly improve health. The prospect of jumping off that building made it clear to me that VR creates unparalleled experiences that can support marketable products like immersive video games. I wondered about what else it could do. Could it help reduce suffering? Could it ease anxiety or stress? If so, could it reduce physical and emotional pain? Could it help battle unchecked narcotic abuse? I thought about the technology itself, which today is portable and relatively cheap. Could it extend care to people who do not have access to a clinic or therapist? By supplementing or replacing drugs, could VR somehow reimagine the boundaries of traditional Western medicine? What would healthcare look like if we took VR seriously?

For decades, a small cadre of scientists at elite universities have been quietly answering these questions. These pioneers, like Walter Greenleaf at Stanford and scores of others profiled in this book, have discovered the surprising health benefits of VR for ailments ranging from burn injuries to stroke to PTSD to schizophrenia to existential anxiety at the end of life, and more. Over five thousand studies reveal that VR has an uncanny ability to diminish pain, steady nerves, and boost mental health—all without drugs and their unwanted side effects.

Until recently, the technology has been too expensive, unreliable, and unwieldy for the research to translate beyond the

pages of academic journals and doctoral dissertations. Now that's all changed. In the past five years, multinational companies such as Facebook, Google, HP, HTC Vive, Sony, and Samsung have invested billions of dollars into developing and expanding the VR industry. As a result, explosive advances have been made in delivering low-cost, portable, and high-quality VR to the masses. Goldman Sachs projects that VR will generate $80 billion in revenue by 2025.[2] We have reached an inflection point where the technology is cheap enough, its quality good enough, and the science voluminous enough to think seriously about leveraging VR to improve human health at scale.

My lab at Cedars-Sinai Medical Center in Los Angeles, and others like it, has been on a journey to study whether and how VR can improve health. In the process of doing so, we created one of the largest medical VR programs in the world. After treating several thousand patients, our team has learned a lot about whether, how, and when to use this technology to support clinical outcomes. By observing how VR influences cognition, we are learning new and surprising ways to optimize health choices, reduce medications, and train more empathic doctors. I wrote this book to describe these findings to a larger audience. I also wrote this book to give voice to patients benefiting from VR and to tell their stories. My hope is to advance this new field of medicine while acknowledging the decades of research and development that laid the foundations for translating VR science into this new clinical reality.

In these pages, I will reveal how we are using VR in the emergency department to help patients with panic attacks, treating women in labor who are seeking to avoid an epidural, and managing patients with orthopedic injuries. I discuss how VR can alleviate the worst kind of pain. I describe how VR can help treat irritable bowel syndrome, support stroke rehabilitation, assist patients undergoing dental procedures, steady tremors, and engage patients with dementia. I tell the story of how we teamed up with a local church to help parishioners lose weight, avoid salt, and lower blood pressure.

But VR also has risks. I have used VR to treat panic attacks, and have also inadvertently *caused* them with VR. I have seen people become dizzy and nauseous while flying over virtual landscapes.

I've seen VR rekindle dark memories in victims of abuse. It can confuse children and the elderly. It can disorient people or cause them to fall. And then there's the more pernicious risk of overpromising and under delivering. I've heard Silicon Valley promoters hail the curative power of VR for all manner of disease. But VR has its limits and we must acknowledge them, understand the evidence supporting VR, and remain optimistic yet cautious about how best to harness this new digiceutical.[3] VR can't always cure what ails you. We can't just VR-away disease. But when used wisely, VR can supplement our ability to heal and help make life worth living.

In the process of telling these stories, *VRx* summarizes hundreds of studies, including our own published work, into actionable insights. The book reviews the evidence supporting therapeutic VR and provides judicious instruction on how to use this immersive technology as a complement to traditional medicine while minimizing risks.

Along the way, we will examine how VR affects the inner workings of the mind, explore the bounds of modern neuroscience, confront the bioethics and risks of VR, recognize the limits of using this technology for patient care, consider how to regulate the burgeoning "VR pharmacy" of immersive digital therapeutics, and predict how VR could impact the practice of medicine for years to come.

I am a physician with expertise in clinical medicine, digital health science, public health, and health economics. But I am not a computer scientist, electrical engineer, or clinical psychologist. This book is about patients and healthcare; it's about whether, when, and how to integrate VR within the very human experience of being sick; it's about how to make doctors more effective and patients better informed when using immersive therapeutics. My goal in this book is to explore the intersection between medicine and VR and to assess the current impact and future potential of this evolving clinical science from my perspective as a doctor. The reader seeking deeper expertise about the theory, history, and computer science of VR is encouraged to review the references included at the back of this book.

At its core, VR is a tool that modifies perception. When used to

correct perceptions that undermine health, VR becomes a radical new therapy to help alleviate suffering from the most intractable diseases of mind and body. In Part I: Our Bodies, Our Selves, we explore the science of VR and discuss how this immersive technology is challenging neuroscientists, psychologists, and philosophers to rethink what it means to be a conscious self. The traditional view of consciousness is that it resides only in the brain. But modern neuroscience reveals the body is more than a mere support scaffolding for the brain; it is the extracranial foundation of our thinking mind. We need our bodies to have our minds. This theory, called embodied cognition, offers a framework to explain how VR alters mind, body, and consciousness through four therapeutic mechanisms that we will consider in Part I. Understanding these mechanisms not only reveals how the brain and body work in tandem, but it also justifies why Western medicine should expand to include VR as a legitimate, science-based intervention for afflictions like anxiety, depression, chronic pain, fibromyalgia, obesity, schizophrenia, and dementia, among many other common disorders.

Next, Part II: Virtual Medicine illustrates how the science of immersive therapeutics is being put to use in clinical practice. We travel to Cedars-Sinai Medical Center, my home base, to learn how VR is allowing our patients to escape the hospital and benefit from positive and emotionally enriching experiences. Through these stories, I describe our lessons learned using VR as a mind-body portal to reduce physical and mental distress. We'll then consider how best to personalize VR in a way that is safe and effective. If VR is truly a new therapy, then it is time to develop and regulate a VR pharmacy. I explain how our team and others are developing virtual pharmacies to tailor immersive therapeutics to individual patients.

Part III: Brave New World explores the humanistic implications of medical VR, highlights new opportunities for training doctors to more effectively deliver care with VR, and envisions how virtual medicine could change our daily life for years to come. I believe that VR has potential to strengthen the humanity in healthcare. It enables doctors to regard patients *as people*; it forces us to rethink the role of doctors as mind-body healers. At first blush, that might seem like an unlikely thesis. In a world of big data analytics,

artificial intelligence, and algorithmic diagnostics, medicine is beginning to feel decidedly unhuman. But VR is a technology unlike any other. In Part III, we explore why VR is an *empathy machine* that allows doctors to engage more meaningfully with their patients and allows patients to become more empathic with themselves.[4]

VRx concludes by exploring the frontiers of therapeutic VR and forecasting how this new field could influence the practice of medicine for years to come. The capacity of VR to engage the embodied mind will only expand in the future. VR will help people using opioids to lower their doses by wearing a sensor that signals the mind when narcotics are paralyzing the gut. Paraplegics will relearn to walk with the help of VR-controlled exoskeletons. People suffering with anxiety or depression will use headsets equipped with artificial intelligence that senses mood and counters harmful emotions with precisely timed, contextually relevant immersive treatments. All of these technologies exist now. It's time to enter this world of virtual medicine.

One last thing: I didn't finish my story about scaling that virtual building. Did I ever jump? Well, sort of. I had to cheat. The VR headset was slightly ill-fitting, which afforded a sliver of light to enter beside my nose. I focused all my attention on the light and located a tiny patch of beige carpet on the floor—a stable point of reality in an otherwise dynamic virtual landscape. This was enough to break the illusion temporarily and permit me to take a shuffling baby step off the rig. And then I plummeted to my virtual death.[iii]

Footnotes

i You can watch this video of his VR experience here: www.virtualmedicine.health/patients-using-vr.

ii A technical definition of VR is the use of a head-mounted display to interact with a computer-generated environment in a realistic manner. A related term is *augmented reality,* or AR, where virtual elements are superimposed over the real world (think of the popular game *Pokémon Go,* where cartoon characters appear to coexist with people). Some use the term *extended reality,* or XR, as an umbrella for VR/AR. Others prefer

spatial computing as a broad term that describes blending immersive tech with the three-dimensional world. The US Food and Drug Administration now calls this field MXR, short for *medical extended reality*. For simplicity, I will call all of this VR. I will also intersperse the term *immersive therapeutics,* which means using VR for treatment purposes as opposed to education or simulation.

iii And it was all caught on video. You can watch the freefall here: www.virtualmedicine.org/freefall.

PART I

Our Bodies, Our Selves

As technology changes everything, we here have a chance to discover that by pushing tech as far as possible we can rediscover something in ourselves that transcends technology.

—Jaron Lanier, computer scientist, author, and the "father of VR," Microsoft Research

CHAPTER ONE

The Second Time I Died

I AM WEARING A CATSUIT WHILE RECLINING IN A CHAIR WITH MY LEGS kicked up on a coffee table in the research laboratory of Mel Slater, a professor of virtual reality at the University of Barcelona. Motion detectors and tiny vibration motors are affixed to my arms and legs. I am being tracked by an array of twelve cameras surrounding my chair that will soon inform a computer how my body is moving in space and time. Slater is standing behind me. A slight, bespectacled man straight out of central casting as the archetypal university professor, Slater speaks in a calm and light British accent. He is reviewing my final flight instructions for what is sure to be a most unusual journey. I've traveled six thousand miles from my home in Los Angeles for this moment.

"Just relax into the experience."

I trust him. I'm ready.

Slater's postdoc, Ramon Oliva, hands me a headset. I put it on and find myself in a comfortable living room with a lit fireplace, plush seats, and wood trimming. There is a mirror on the wall in front of me that reflects the image of my pixelated doppelgänger. And there's the coffee table under my feet, just where I left it.

"Okay, move your legs around on the table," says Oliva.

I oblige. In perfect synchrony, I see my own legs dance about on the digital tabletop. For a moment, I cannot tell whether those legs are mine. They *look* like my legs. They *act* like my legs. But *are they* my legs? I wiggle them back and forth. They move as expected. Yes, those are my legs. At least, I'm pretty sure they're

my legs. If not, then whose legs could they be?

Next, little blue balls drop from the ceiling. Pop! I feel a ball hit my foot. A vibration engine in the suit fires at the same moment the virtual ball strikes my virtual body. Pop! Pop! Two more balls hit my left and right hand. Pop! Pop! Pop! Balls keep falling from the ceiling and tapping my limbs.

I think for a second: What is happening here? A computer somewhere in this room is running thousands of lines of code that are creating an illusion of spherical balls. Yet, those virtual balls—those pixelated clusters—are hitting my body with a very real physical force. I am *feeling* those digital balls. Those balls are real. This body is real. It is *my* body. The physical and virtual worlds are becoming indistinguishable. They are starting to feel like one unified existence.

I am now locked into my digital self. I have assumed what Slater calls full body ownership. The synchronous visual and tactile stimulation has convinced my brain that it now resides in a virtual head, in a virtual body, in a virtual room. My virtual feet are on a virtual coffee table. I see my body in a virtual mirror. I exist in this virtual world. This virtual world is a real world.

I will not soon forget what happens next. It is indelible, even mystical. I will do my best to describe it.

I start to move. And I mean *I* start to move, but my body stays put. In a steady backward flow, my personhood—my thinking self—begins to pull away from my body. I imagine sinews stretching, pulling, and snapping as my body resists the separation. It cannot hold on. I vacate my body and watch it as my consciousness drifts up toward the ceiling. I sense a brief existential crisis, a sort of Cartesian fit where my mind and body seek to reconcile the separation. For the first time in my life, I am disconnected from myself. I cannot tell if this is a physical or metaphysical cleavage, but it doesn't really matter. It *feels* as if I have been extracted from my body. I am floating like a balloon. Now I am up in the ceiling looking down upon my lifeless self. I am moving my hands, and those balls keep following me up to the ceiling and continue to strike my limbs. I've become an ethereal and disembodied entity hovering above my shell of a body below. That body down there is not moving. My arms are moving—I can feel them—but that body is not. I am in motion but that body is still. That body is

mirror no longer made sense. I saw an inanimate body in that mirror. I watched myself pass through my motionless avatar and float behind it. I watched myself die. In the process, Slater's brain-in-a-vat computer simulation coaxed my brain into accepting an alternative reality. I was no longer able to tell where my body ended and the world began. My physical sense of self in the world —my literal coordinates in space—were temporarily unbounded, allowing my mind freedom to roam in ways it never knew were possible. Even now, long after the demonstration finished, I feel differently about my relationship to my body. I can now say I've felt an out-of-body experience, and I can testify that it reduced my own personal fear of death, if even just a tiny bit. Understanding *how* it did this offers insights into the power of VR to alter mind and body, in both the short and long term. It helps us explain the unique ways that immersive therapeutics can improve health.

We begin this scientific journey by contemplating how a dime-store mirror can profoundly transform human consciousness.

The discovery that culminated in my mystical experience in Barcelona traces back to an astonishing yet simple study conducted by V. S. Ramachandran in the mid-1990s at the University of California, San Diego.[4] A clinical neurologist and cognitive neuroscientist, Ramachandran was struggling to find an effective treatment for his patients suffering from phantom limb pain. Phantom limb is a maddening condition where people who suffer an amputated arm or leg continue to feel its ghostly presence long after the appendage is gone. For some patients, the phantom limb feels extremely painful—even spastic—like a hand balled up in a tight fist. Yet, there is no hand. There is no fist. In a bid to restore a sense of corporeal wholeness, the brain hallucinates the continued presence of a false limb.

Ramachandran and his colleagues had a conceptual breakthrough: if they could just fool the brain into thinking there was a *real* limb present after all, then they could offer patients a chance to regain control over their phantom sensations. The researchers did this by creating a simple and elegant device they called a virtual reality box, also dubbed a mirror box. In the case of a missing arm, it worked like this: patients placed their remaining, healthy arm through a hole cut in the side of a cardboard box. The

box was split into two chambers with a mirror affixed vertically along the separation wall. When positioned correctly, the healthy hand reflected off the mirror and created the appearance of a complementary second hand exactly where it should be. The following image shows a healthy left hand reflecting off the mirror and simulating the presence of a healthy right hand. If you look carefully, you can see that the right arm does not extend into the box at all; the amputated stump stops short of the box, yet the reflected hand appears like an extension of the missing limb.

Ramachandran's first mirror box patient was a fifty-five-year-old man with unrelenting sensations of spasms in his phantom arm. These sensations persisted for months after the amputation. The patient viewed his illusory hand in the mirror while attempting to resurrect his phantom hand. On the very first attempt, he reported that all movement had come back into his missing limb and that the pain subsided. Soon after, Ramachandran tested the mirror box with a twenty-eight-year-old man also suffering from severe phantom limb pain. His pain had persisted for nine years after a traumatic arm amputation. The first time he tried the box, the patient described the experience as "mind boggling" and reported that his arm was "plugged in again" and no longer felt "like it's lying lifeless in a sling."[5] After three weeks of therapy, his phantom arm pain disappeared completely. It never returned. And with that single experiment, Ramachandran laid the scientific groundwork for therapeutic VR. He had discovered a rudimentary yet revolutionary technique to alter consciousness.

Ramachandran's "virtual reality box."

Much of the promise of VR is predicated on the fundamental insights gained by the mirror box experiments. Our sense of self—our perception of where we physically begin and end—is a substrate for feelings like pain and anguish, and it can be easily manipulated. Our very coordinates in space, which we take for granted as objective, essential, and absolute, are less certain than

we might imagine. Virtual experiences have a remarkable ability to undermine certainty. This power may confuse or deceive, but if employed properly, it can strengthen cognitions and enhance well-being.

Admittedly, it seems like a big jump between using a mirror for a phantom limb and teleporting an entire body to the ceiling. To tell the next part of this story, we turn to the unlikely combination of a rubber hand, two paintbrushes, and a knife.

When Henrik Ehrsson was a child he wondered whether God had played a trick on him by placing his soul in his brother's body, and vice versa. He felt there had been a cosmic mix-up that left his mind in the shell of the wrong person. This curious thought caused Ehrsson to ask some heady questions as a child, like, "How do I know that this is my body, and not my brother's body? Why does it feel like I am located inside this body? And how do I experience the world through my own eyes?"[6]

So this little boy became interested in the brain and what it means to have a conscious human mind. He wondered how we can recognize that our limbs are part of our own body, and how we sense the physical location of our self within our body, and not elsewhere. Forty years later, Ehrsson is an esteemed professor of cognitive neuroscience at the Karolinska Institute in Sweden, where his lab is investigating the nature and boundaries of personhood. His provocative research challenges what it means to be a thinking mind within a physical body. Ehrsson's work is important because it provides the missing link between Ramachandran's mirror box and Slater's virtual out-of-body experience.

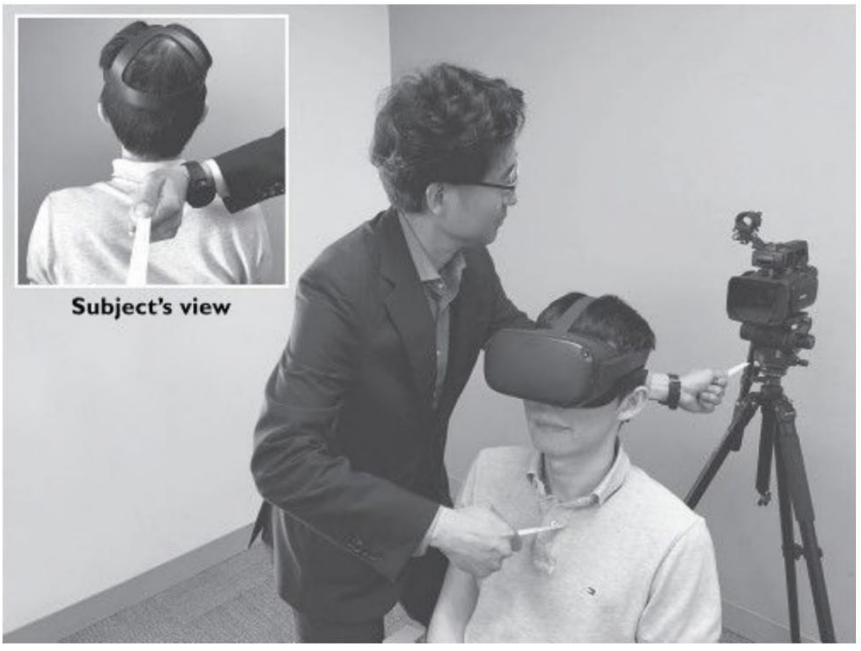
When Ehrsson began planning experiments to address his childhood curiosities, he came across a fascinating 1998 study published in *Nature* by Matthew Botvinick from the University of Pittsburgh and Jonathan Cohen from Carnegie Mellon University.[7] Inspired by the work of V. S. Ramachandran, Botvinick, and Cohen created a cognitive parlor trick that had the opposite effect of the mirror box illusion. Rather than disowning a false limb and extinguishing its misleading sensations, their experiment *induced ownership* of a false limb and removed ownership of a real limb. The bizarre result was a convincing illusion of transferring body

ownership from one's real arm to a fake arm.

Here's how it worked: Botvinick and Cohen sat people down in a chair and asked them to rest their arms on a table. Then they positioned a vertical barrier between the subject's eyes and one arm, putting the limb out of sight. Next, they placed a lifelike rubber hand on the table near the real hand, but on the visible side of the vertical barrier. The subject could not see the real hand, but instead viewed a life-sized fake hand in nearly the same location as the true hand. Once the setup was complete, the researchers stroked the rubber hand and real hand at the same time using a pair of fine-tipped paintbrushes, taking care to synchronize the brush strokes as closely as possible. This photo shows the experimental setup.

Experimental setup for the "rubber hand illusion."

Botvinick and Cohen found that before long, their research subjects were convinced the rubber hand was their own. They had embodied a gag appendage as an extension of the real body. When subjects were asked to close their eyes and point to their real hand, they were more likely to point to the fake hand, not their own, demonstrating the limb transfer illusion was complete. Just



Experimental setup for the "phantom body illusion."

People in the chair felt displaced to the location of the camera behind their actual coordinates. They experienced a radical out-of-body illusion where they vacated their physical body. Rather than removing ownership of a phantom limb, as Ramachandran achieved with his mirror box, Ehrsson caused ownership over a *phantom body* using a souped-up version of the rubber hand illusion.

Ehrsson conducted additional experiments to explore the body-swap illusion. In one study, he used a VR headset to transport people into the body of a rubber mannequin.[11] Then he attacked the mannequin with a knife, causing people to react violently. In another experiment, he shrunk people down to the size of Barbie and Ken dolls, literally causing them to feel like Alice in Wonderland surrounded by oversized objects.[12] Other researchers followed suit, showing that people could feel a body swap with each other using a VR headset as the illusory conduit. An interdisciplinary group of scientists, artists, and designers created *The Machine to Be Another*, a program that allows anyone to experience the world from the viewpoint of another through a

head-mounted display.[13] The program features a library of what the developers call embodied storytelling experiences. The effect is well captured by Aaron Souppouris, a reporter for *The Verge*, who described his experience of switching gender:

> I am no longer Aaron Souppouris. I am a woman. I am a stranger. I stare down at the mask I hold in my hands, struggling to comprehend how those hands, which are clearly not mine, are allowing me to feel its curves and cracks. As I glance at the mirror in front of me, my new lip piercing glimmers under the harsh fluorescent lights. This is not a fever dream, not a hallucination, not even a video game. This is *The Machine to Be Another*.[14]

After careful observation of these body-swap experiments, Ehrsson identified *three rules* that enable the illusion. First, he discovered that the tactile stimuli must be delivered simultaneously between the real and false bodies. If there is a delay between the visual and actual touches, then the illusion is violated. Second, the stimuli need to be in the same direction. For example, the brain will not accept a virtual hand if it's stroked in the opposite direction of the real hand. Third, the virtual body needs to be very near the real body. If there is too much distance between the bodies, then the brain sees through the ruse. He called these key principles the *temporal rule*, *spatial rule*, and *distance rule* of body transfer.[15] When these three conditions are met, the brain is tricked into relocation.

Ehrsson's three rules offer a fundamental recipe for shedding the self. When all three criteria are satisfied we can patch into a new reality. Now think back to my out-of-body experience. Professor Slater fooled my brain using a combination of insights from Ramachandran's mirror box, Botvinick and Cohen's rubber hand, and Ehrsson's body-swap rules. Using the temporal rule, he synchronized the virtual ball strikes with the sense of touch that was created by vibration engines in the catsuit. Using the spatial rule, he coordinated the directional movements of my actual and virtual legs on the coffee table. Using the distance rule, he started the illusion very close to my own body—even *inside* my own body—

and only then distanced myself from, well, myself. The result was a complete out-of-body experience.

But more than that, Slater induced a transcendent, even mystical, experience. It was more than a parlor trick. Beyond the physical wonder of spatial displacement, I had the emotional experience of confronting mortality. Just how did one lead to the other? It is this leap, from sensorial to emotional, where we begin to appreciate not just the physical impact of VR on the body but also its therapeutic benefits on the mind.

Speaking of leaps, I have virtually died twice in this book so far: first, after virtually leaping off a building. Then, again, after teleporting to the ceiling and observing my lifeless body from above. I was petrified in the first instance. I felt oddly transcendent in the second. In both cases, VR created powerful cognitions *and* strong physical sensations. These were full body experiences.

I don't think I was a brain-in-a-vat in either scenario. That just can't be right. Both experiences required that I have a body, not just a brain. I reside in a physical body, and that body affects everything I think and know. It is shortsighted to think of the brain as a bundle of nerves riding atop a physiologic machine. Instead, it is an integrated part of the machine that is intertwined and harmonized within the body as a whole.

In 1641 the French philosopher René Descartes famously concluded, "I think, therefore I am." It was his way of saying that he believed the thinking mind was made of immaterial stuff that was categorically separate from the physical material of the body. Descartes proposed that the mind and body interfaced at the pineal gland, a tiny structure buried deep in the brain. This view became known as dualism, meaning the mind and body are two distinct entities. Cartesian dualism dominated Western theories of mind for centuries. Turns out it was wrong. Modern neuroscience suggests the story is more complex and interesting. Our sense of self—our very consciousness—depends not only on having a brain but also on having a body. We need our bones, tendons, ligaments, viscera, and sense organs to be conscious.

You know this to be true if you've been to a rock concert and *felt* the low-octave notes of a bass guitar pulsing through you. You

can experience the same thing with the reverberating chords of a cathedral's pipe organ. We can "hear" these instruments with our body. The sounds seem like they come straight up from the floor and into your seat. Somehow, the physical experience of a vibrating derriere generates sound in our mind.

Not just sensations, but even judgments are modified by the physical state of our bodies. In a remarkable experiment conducted by University of Cambridge neuroscientist Simone Schnall, research subjects stood at the bottom of a steep hill and were instructed to rate its angle of ascent.[16] On its face, this task seems like a test of geometric reasoning more than a measure of bodily fitness. But Schnall had a theory that the amount of glucose circulating in the body might affect judgment about the steepness of the hill. After all, if you have more energy-producing glucose coursing through your veins, then you might be better prepared to size up and ascend the incline. The research team divided subjects into two groups: one received a purple drink full of glucose, and the other received a purple drink full of artificial sweetener. Sure enough, those receiving the sugar boost were more likely to rate the angle of the hill correctly. In contrast, the sugarless group rated the hill to be steeper than it actually was.

Even the bacteria in your colon can affect how you think and feel. As a gastroenterologist, I spend a lot of time studying the connections between the gastrointestinal system and the brain.[17] Both sides communicate all day long. On the gut side, billions of bacteria affect us in unexpected ways. My former colleague Kirsten Tillisch discovered that replacing bad bacteria in the gut with good bacteria can change how the brain responds to stress.[18] Compared to a group of research subjects who didn't consume a probiotic yogurt, those who did exhibited diminished activity in the brain's emotion centers when exposed to faces of people in distress. This suggests a dampened fear response. Such experiments demonstrate that the mind is very much dependent on the body, and in this case, on the meta-notion of bodies within the body.

All of these examples support a theory called embodied cognition, which is the idea that everything we think about and know is a result of not just having a brain but also because that brain is connected to the rest of the body.[19] MIT neuroscientist Alan Jasanoff describes this theory as "thinking, outside the box,"