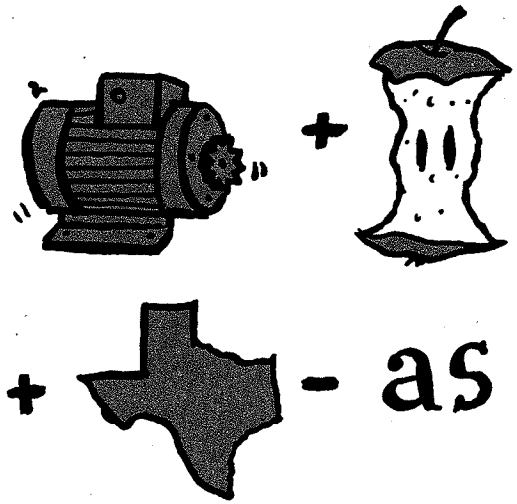
CHAPTER FIVE

The Brain's Motor

Now that we've learned about some internal brain structures, it's time to explore how the brain interacts with the outside world. It does so primarily through movement, which involves transmitting messages to the body via nerves.



George Dedlow. The dimes and quarters and silver dollars trickling into Philadelphia's "Stump Hospital" often came with notes of sympathy for George Dedlow. Every man crowding around the hospital's front door wanted to tip his hat to, and every woman blow a kiss at, George Dedlow. The hospital superintendent pleaded ignorance, but well-wishers never tired of asking about Captain George Dedlow.

The cover story of the July 1866 issue of *The Atlantic Monthly* was "The Case of George Dedlow," one of the saddest of the Civil War's many sad tales. In the introduction Dedlow claimed that he'd originally tried to publish his report in a proper medical journal, and after a number of rejections had transformed the piece into a personal narrative. The action began with Dedlow joining the 10th Indiana Volunteers as assistant surgeon in 1861, despite having completed just half of medical school. The U.S. military was so desperate for surgeons then—it had just 113, a small fraction of the 11,000 that both armies would require during the war—that most units snatched up even tyros like him.

One night in 1862, Dedlow writes, while stationed near a malaria-ridden marshland south of Nashville, he received orders to sneak through twenty miles of enemy lines and secure some quinine. Seventeen miles in, he stumbled into an ambush and got shot in both arms—in his left biceps and right shoulder—and passed out. He woke to find the rebels, like centurions at the cross, drawing lots for his hat, watch, and boots. They eventually dumped him into a medical cart, which rattled him 250 miles south to an Atlanta hospital. His right arm throbbed the whole journey, burning as if it were being held near flames; he found relief only by dousing it with water. The burning continued for six weeks, and the pain became so acute that when his doctor suggested amputating the arm, Dedlow agreed despite the lack of ether.

After recovering, Dedlow was exchanged for a Southern captive.

Rather than return home, the one-armed doctor took just thirty days of furlough and rejoined his unit. The Indiana boys ended up in Tennessee again, and once again Tennessee did not treat them well. During one of the bloodiest battles in U.S. history, near Chickamauga Creek, Dedlow's unit got caught in intense crossfire while scampering up a hill. Clouds of gun smoke enveloped them, punctured by red lightning and rifle thunder. This time Dedlow got shot through both legs, one of the battle's 30,000 casualties.

He awoke beneath a tree, in shock, with two shattered femurs. Orderlies gave him brandy and cut away his pantaloons while two surgeons—wearing navy-blue uniforms with green sashes about the waist—bent to examine him. They grimaced and walked away, damning him by triage. Sometime later, though, Dedlow felt a towel against his nose, then inhaled the fruity chemical pinch of chloroform. Two other surgeons had returned, and although Dedlow didn't realize it, they'd decided to amputate both legs right there in the field.

Confederate surgeons usually performed "circular" amputations. They made a 360-degree cut through the skin, then scrunched it up like a shirt cuff. After sawing through the muscle and bone, they inched the skin back down to wrap the stump. This method led to less scarring and infection. Union surgeons preferred "flap" amputations: doctors left two flaps of flesh hanging beside the wound to fold over after they'd sawed through. This method was quicker and provided a more comfortable stump for prosthetics. Altogether, surgeons lopped off 60,000 fingers, toes, hands, feet, and limbs during the war. (In Louisa May Alcott's *Hospital Sketches,* one Union soldier proclaims, "Lord!, what a scramble there'll be for arms and legs, when we old boys come out of our graves on the Judgment Day.") A typical amputation lasted maybe four minutes, and on the worst days a surgeon might do a hundred—some in fields, some in barns, stables, or churches, some on nothing but a plank suspended between two barrels. In borderline cases surgeons erred on the side of amputating, since the mortality rate for compound fractures was abysmal. Not

that the mortality rate for amputations was good. Sixty-two percent of double thigh amputees died.

To his later sorrow, Dedlow woke up after his double thigh amputation. But it was at this very moment—in his fog, before he realized what had happened—that Dedlow's tale swerved and began to transcend a typical soldier's sob story. For despite the operation, Dedlow awoke with cramps in both calves.

He hailed a hospital attendant, gasping, "Rub my left calf."

"Calf? You ain't none," the attendant answered. "It's took off."

"I know better. I have pain in both legs."

"Wall, I never. You ain't got nary leg." With this, Dedlow recalled, "he threw off the covers and, to my horror, showed me..."

Faintly, Dedlow dismissed him. He lay back, ill, probably wondering if he'd gone mad. But damn it, he'd felt the cramps in both legs. They'd *felt* intact.

Soon another tragedy befell him. Dedlow's left arm had never quite healed right after the ambush near Nashville and continued to weep pus. Now, in the dirty recovery ward, the arm contracted "hospital gangrene," an aggressive disease that could eat away flesh at rates of a half inch per hour. Almost half of all victims died in their beds, and against his better judgment, Dedlow let his doctors save his life by amputating his last remaining limb. He awoke to find himself, he later sighed, a diminished thing, more "larval" than human.

In 1864, Dedlow was transferred to Philadelphia's South Street Hospital—nicknamed "Stump Hospital" for all the amputees limping through its corridors. But even within Stump, Dedlow's helplessness set him apart: orderlies had to dress him every morning, had to drag him to the toilet at all hours, had to blow his nose and scratch his every itch. Virtually sedentary—orderlies had to carry him everywhere in a chair—he needed almost no sleep, and his heart beat just forty-five times per minute. With so little body to nourish, he could barely finish the meals that orderlies had to feed him bite by bite.

Yet he could somehow still feel that missing four-fifths of himself—still feel pain in his invisible fingers, still feel his invisible toes twitching. "Often at night I would try with one lost hand to grope for the other," he recalled, but the ghosts always eluded him. Out of curiosity he interviewed other Stump inmates and discovered that they felt similar sensations—stabbing, cramping, itching—in their missing limbs. Indeed, the ungodly aches in their ghost arms and ghost legs often made their missing limbs more insistent and intrusive than their real ones.

Dedlow didn't know what to make of this phenomenon until, a few depressing months later, he met a fellow invalid, a sergeant with washed-out blue eyes and sandy whiskers. They struck up a conversation about spiritualism and communicating with departed souls. Dedlow scoffed, but the sergeant talked him into attending a séance the next day. There, after some preliminary mumbo jumbo, the mediums started summoning up people's dead children and late spouses—a trick that often reduced the participants to hysterics. The mediums also relayed messages from the beyond, Ouija board–style, by pointing to letters on an alphabet card. They then listened for a confirmatory knock (spirits can knock, apparently) upon reaching the correct letter. Eventually a wan medium with bright red lips named Sister Euphemia approached Dedlow. She asked him to silently summon to mind whomever he wanted to see. All at once, Dedlow says, he got a "wild idea." A moment later, when Euphemia asked if Dedlow's guests were present, two knocks sounded. When Euphemia asked their names, they tapped out, cryptically, "United States Army Medical Museum, Nos. 3486, 3487."

Euphemia frowned, but Dedlow, a war surgeon, understood. As reported by Walt Whitman (and many others who couldn't shake the image from their minds), hospitals routinely piled all their amputated limbs outside their doors, forming cairns of legs, arms, and hands. Rather than bury them, though, the army packed the flesh into barrels of whiskey and shipped them to the Army Medical Museum, which catalogued them for future study. Dedlow's legs were apparently numbers 3486 and 3487, and per his wish, Euphemia had summoned them to the séance.

At this point the story swerved again. Dedlow suddenly cried out, then began to rise in his chair. He reported feeling his ghost legs beneath him, reattaching themselves to his femurs. A moment later his torso rose, and he began staggering forward. He felt unsteady at first—after all, he noted, his legs had been soaking in booze. But he crossed half the room before they dematerialized, at which point he collapsed.

Here Dedlow ended his story abruptly. Rather than cheer him, the brush with the other side only reminded him of what he'd lost, and he felt even more diminished. As he told the orderly transcribing his story, for any man "to lose any part [of himself] must lessen... his own existence." He concluded, "I am not a happy fraction of a man."

Although rejected by medical journals, "The Case of George Dedlow" panged people—pierced them in a way that an academic paper never could have. The Civil War had maimed and disfigured hundreds of thousands of men. Nearly everyone had a brother or uncle or cousin whose wounds had never set right. Moreover, as the first well-photographed war, the Civil War branded the country's psyche with indelible images, of stumps and naked wounds and holes where there shouldn't be holes. These macabre photographs, in museums, in magazines, were in some ways the heir to Vesalius's *Fabrica.* Except they didn't celebrate the human form so much as catalogue its destruction.

And yet for all their power, these images of broken men remained silent—until George Dedlow gave them voice. His story spoke for every misshapen soldier in every village square, for every sobbing wreck in every parish pew, for every amputee whose ghostly limb made him scream out in the night.

So from far and wide that summer of 1866, donations arrived in Philadelphia for Captain Dedlow. Crowds even gathered around Stump's front door, pleading to meet their hero—and were stunned to hear that Dedlow didn't exist. With much regret, the hospital superintendent told the throngs that there was no George Dedlow among his patients. Nor could he find any George Dedlow in the hospital archives. For that matter, the military had searched its records

and could find no cases, anywhere, of any quadruple amputees. The tale in *The Atlantic Monthly*, the superintendent explained, was fiction. The only authentic thing about it was Dedlow's disorder, a disorder medicine had never taken seriously before. The only real detail was, paradoxically, the phantom limbs.

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For as long as human beings have waged wars, surgeons have lopped off limbs—although until recently soldiers rarely lived to speak of the experience. Similar to his reforms with treating gunshot wounds, Ambroise Paré convinced surgeons in the 1500s not to cauterize fresh stumps by dunking them in boiling oil or sulfuric acid. Instead Paré promoted ligation, which involved tying off the severed ends of arteries and sewing the stump shut. This greatly reduced blood loss and infection (not to mention agony), and meant that amputees finally had a decent chance of surviving. Paré became so confident of their survival, in fact, that he started designing fake limbs for them, some of which, thanks to gears and springs, actually moved. (His line of substitute ears, noses, and penises remained immobile, however.)

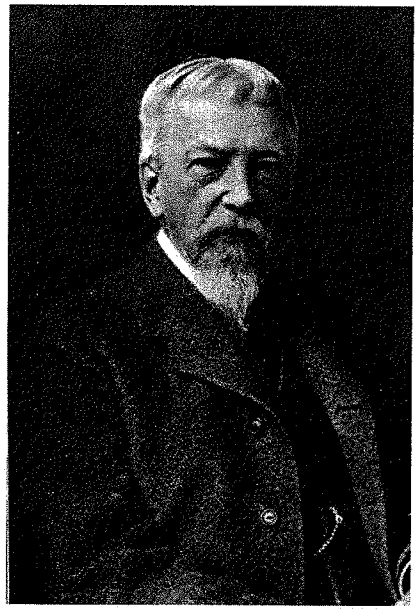
Not surprisingly, the first stray references to phantom limbs appeared in Paré's writing, and they quickly became an object of fascination for philosophers. René Descartes dabbled in neuroscience at times—he famously declared the pineal gland,* a pea-sized nugget of flesh just north of the spinal cord, the earthly vessel of the human soul—but he also ruminated on the implications of phantom limbs. One story, about a girl who lost her hand to gangrene but woke up moaning about the pain there, especially shook him. This and related stories "destroyed the faith I had in my senses," he wrote—to the point that he stopped trusting the senses as a sure route to knowledge. From there it was but a small step to *cogito ergo sum*, a declaration that he had faith only in his powers of reasoning.

British naval hero Horatio Nelson also leapt from phantom limbs to metaphysics. During the biggest blunder of his career—an attack

on Tenerife, in the Canary Islands, in 1797—a musket ball shredded his right shoulder, and a surgeon had to hack it off in the dim hold of a rolling ship. For years afterward Nelson felt his phantom fingers digging into his phantom palm, causing excruciating pain. He actually took succor from this, citing it as "direct proof" that the soul existed. For if the spirit of an arm can survive annihilation, why not the rest of a man, too?

The physician Erasmus Darwin (grandfather of Charles), philosopher Moses Mendelssohn (grandfather of Felix), and writer Herman Melville (in *Moby-Dick*) all touched on phantoms as well. But the first clear clinical account of phantom limbs—he even coined the term—came from Civil War doctor Silas Weir Mitchell.

Weir Mitchell—he hated the name Silas—grew up a dreamy lad in Philadelphia. He suffered from phantasmagoric nightmares after hearing about the "holy ghost" in church, and he dabbled in both poetry and science. He especially loved the bright, pretty concoctions



Neurologist Silas Weir Mitchell.

his father, a doctor, would conjure up in his private chemical laboratory. Mitchell eventually decided to enter medical school—over the objections of his old man, who thought he wouldn't stick it out. Mitchell did, and even did rigorous medical research on snake venom before settling into private practice in Philadelphia in the 1850s.

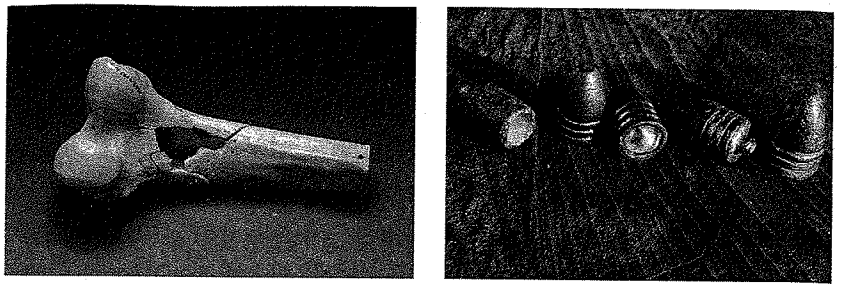
Despite hating slavery, Mitchell didn't take the outbreak of the Civil War that seriously. Like many Americans, north and south, he assumed his side would whip the other in short order, and that would be that. He soon realized his mistake and became a contract military doctor. After a few months of making rounds to different military hospitals, Mitchell discovered he had a knack for neurological cases, cases most doctors loathed, even feared. So as the bodies kept piling up—Philadelphia's patient population reached 25,000 during the war—he helped found a neurological research center, Turner's Lane Hospital, on a dirt road outside Philadelphia in 1863.

One patient called Turner's Lane "a hell of pain"—a fair assessment, although this was partly by design. The military arranged for most cases of neurological trauma to end up there, and Mitchell preferred to trade away "easy" cases to other hospitals for more challenging ones, swapping convalescents with simple stomach wounds for thrashing epileptics and howling infantrymen with shattered skulls. Turner's, then, became the hospital of last resort, and although many of his patients never recovered, Mitchell found the work rewarding. He became an expert on nerve damage and especially on phantom limbs, since the Civil War produced amputees on an unprecedented scale.

A few months after Turner's Lane opened, Mitchell rushed over to the Battle of Gettysburg, where he saw for himself why the Civil War left so many limbless. Before the 1860s most soldiers used muskets. Muskets loaded from the front and they loaded quickly, since the bullets had smaller diameters than the barrels. This gap between bullet and barrel, however, produced swirling air currents that spun the bullet chaotically as it zipped down the barrel's length. As a result, the bullet curved when it emerged from the muzzle, like a doctored baseball. This made aiming all but pointless: as one Revolutionary War veteran sighed, "[when] firing...at two hundred yards with a common musket, you might as well just fire at the moon."

The other common type of military gun, the rifle, had the opposite problem: it was accurate—soldiers could plug a turkey's wattle at several hundred yards—but slow. The key to the rifle's dead aim was the inner barrel, which had tight, spiraling grooves running along its length; these grooves spun a bullet aerodynamically, like a football. For the grooves to work, however, the bullet and barrel had to be in close contact. This required bullets and barrels of basically the same diameter—which made them a bitch to load. Soldiers had to ram the bullets down the barrels inch by inch with rods, a laborious process that led to lots of jamming and swearing.

A few enterprising soldiers finally combined the best of rifles and muskets in the 1800s. An Englishman stationed in India noticed that warriors often tied hollow lotus seeds to their blow darts. When fired with a puff, the seeds ballooned outward and hugged the peashooters' barrels as they moved forward, much like a rifle. Inspired, the Englishman invented a metal bullet that had a hollow cavity, and in 1847 a Frenchman named Claude-Étienne Minié (*min-YAY*) greatly improved the design. Minié's bullets were smaller than a rifle's barrel, so they loaded quickly. At the same time, like the lotus seeds, they expanded when fired (from a punch of hot gas) and hugged the barrel's grooves as they hurtled forward—making the guns uncannily accurate. Worse, because the bullets had to expand, Minié made them out of soft, pliable lead. This meant that, unlike those hard Russian bullets forty years later, Minié bullets deformed upon impact, widening into blobs and shredding tissue instead of passing clean through. The result was an awesome killing machine. Based on its accuracy, its rate of fire, and the likelihood of a gaping wound, historians later rated the Minié bullet/rifle combination as three times deadlier than any gun that had ever existed. And those soldiers who didn't die had their limbs shattered beyond repair.



Left: A femur bone, shattered and amputated after being struck with a Minié bullet. Right: Minié bullets, made of lead. (National Library of Medicine)

In 1855 the secretary of war, Jefferson Davis, selected the Minié/rifle combo as the U.S. military's official arms and ammo. Six years later, as president of the Confederacy, Davis no doubt rued his earlier enthusiasm. Manufacturers started churning out untold numbers of cheap Minié bullets—which soldiers called "minnie balls"—and factories in the North especially started stamping out millions of Minié-compatible rifles, which butchered boys almost from sea to shining sea. The guns weighed ten pounds, cost $15 ($210 in today's money), and measured about five feet long. They also had an eighteen-inch bayonet, which was risible, since this gun more or less rendered the bayonet a foolish relic: rarely could soldiers get close enough to plunge one in anymore. (Mitchell once estimated that mule kicks hurt more soldiers during the Civil War than bayonets.) The Minié bullet also pushed cannons far back behind the infantry lines and greatly diminished the power of the mounted cavalry charge, since horses were even easier to pick off than humans. By some estimates Miniés killed 90 percent of the soldiers who died on the battlefield.

Unfortunately, many Civil War commanders—steeped in antiquated tactics and drenched in the romance of Napoleonic charges—never adjusted to the new reality. Most notoriously, on the day Mitchell arrived at Gettysburg, some 12,500 Confederate soldiers stormed a stone fence held by the Union. Pickett's Charge. Among other troops, soldiers with piles of minnie balls were waiting, and they

pulped the guts and pulverized the bones of the chargers up and down the line.

An injured soldier might languish for days before a stretcher team or ambulance wagon lugged him to a clinic. There, he might wait hours more until a surgeon in a bloody apron appeared, a knife between his teeth. The surgeon would probe the wound with fingers still crimson from the last patient, and if he decided to amputate, one assistant knocked the patient out with chloroform or ether, another put the limb into a headlock, and a third got ready to clamp the arteries. Four minutes later, the limb fell. The surgeon hollered "Next!" and walked on. This work might continue all day—one Kentucky surgeon remembered his fingernails getting soft from absorbing so much blood—and fresh graves ringed every hospital.* Walt Whitman recalled the crude tombstones, mere "barrel-staves or broken boards stuck in the dirt."

After Gettysburg, Mitchell returned to Philadelphia to deal with the deluge of casualties. And although he continued his private practice (military work paid just $80 per month), he spent the better part of most days at Turner's Lane, arriving at 7 a.m. for an hour of rounds, then returning around 3 p.m. and often staying until midnight. He spent hours writing up case reports as well—an illuminating experience. His early research training had emphasized rigor and data, but Mitchell found he couldn't capture these cases with numbers and charts alone. Only narrative accounts could get at what injured soldiers really felt. The narratives affected him so profoundly, in fact, that in later years he began writing novels about his experiences, and drew on these case reports for inspiration.

Mitchell did his best and most original research on phantom limbs. Before his time, relatively few people admitted to them, since they risked being pegged as loopy. A more sympathetic Mitchell determined that 95 percent of his amputees experienced ghost limbs. Interestingly, though, the distribution of phantoms wasn't equal: patients felt upper-body phantoms more vividly than lower-body

phantoms, and felt phantoms in the hands, fingers, and toes more acutely than phantoms in the legs or shoulders. And while most men's phantoms were paralyzed—frozen into one position—some soldiers could still "move" their phantoms voluntarily. One man would raise his phantom arm instinctively, to grab for his hat, whenever a gust kicked up. Another man missing a leg kept waking up at midnight to use the privy; groggy, he'd swing the phantom leg onto the floor and tumble.

Mitchell also probed phantom pain. Cramps or sciatica might race up and down the phantom, in waves lasting a few minutes. Less acute, but possibly more maddening, people's phantom fingers or feet would start itching—itches impossible to scratch. Stress often exacerbated the discomfort, as did yawning, coughing, and urinating. Perhaps most important, Mitchell determined that if a soldier had felt a specific pain right before his amputation—like fingernails digging into his palm, a common result of muscle spasms—that same pain often got "stamped" into his nerves, and would persist for years afterward in the phantom.

To explain where phantoms came from, Mitchell suggested a few interrelated theories. His patients' stumps often had raised growths on them where the underlying nerves had been severed. These "buttons" proved quite sensitive to the touch; they prevented many men from wearing prosthetics. Mitchell deduced from this touchiness that the nerves beneath must still be active—and still pinging the brain. As a result, part of the brain didn't "know" the limb had gone AWOL. As further proof, Mitchell cited a case where he'd actually resurrected a patient's phantom. This man had stopped feeling his phantom arm years before (as sometimes happened), but when Mitchell applied an electric current to the stump buttons, the man felt his former wrist and fingers suddenly materialize at the end of his stump—exactly as George Dedlow had at the séance. "Oh, the hand, the hand!" the man hollered. This indicated that the brain did indeed take cues from the stump.

Mitchell also implicated the brain itself in phantom limbs, a crucial development. Many a veteran, despite losing his dominant hand decades before, kept eating meals and writing letters with that hand in his dreams. Unlike stump irritation, this was a purely mental phenomenon and therefore must have its origins within the brain. Even more arresting, Mitchell discovered that some people who'd lost a hand or leg in infancy, and therefore had no memory of it, nevertheless experienced phantoms. Mitchell concluded from these cases that the brain must contain a permanent mental representation of the full body—a four-limbed "scaffold" stubbornly resistant to amputation. The brain's private metaphysics, then, trumped physical reality.

Later work by other scientists confirmed and built upon Mitchell's insights. For instance, Mitchell focused on how preamputation pain or paralysis can carry over into the phantom, but later scientists found that less pernicious sensations can be stamped onto the ghost as well. Some amputees feel phantom wedding bands and Rolexes, and people whose arthritic knees or knuckles allowed them to sense impending thunderstorms can often pull off the same trick with their phantoms. Moreover, neuroscientists have confirmed Mitchell's guess that the brain contains a hardwired scaffold of the full body, since children born without arms or legs sometimes still feel phantoms. One girl born without forearms did arithmetic in school on her phantom fingers.

Doctors have also catalogued phantoms in brave new places. Dental extractions can produce phantom teeth. Hysterectomies can produce phantom menstrual cramps and labor pains. After colorectal procedures, people might feel phantom hemorrhoids and bowel movements and rumbling phantom flatulence. There are also phantom penises, complete with phantom erections. Most phantom penises arise after penile cancer or accidents with shrapnel that most of us prefer not to think about. But unlike phantom limbs—which are often frozen into claws, and excruciating—most men find a phantom penis pleasurable. And they're so realistic that even decades after the penis is

shorn, some men still walk a little funny when they get aroused. Heck, some men's phantom penises lead to real orgasms. All this showed that quite a few sensations and emotions in the brain can be tied up with phantoms.* The work furthermore helped shift the focus of phantom limbs away from the stump and toward the brain itself.

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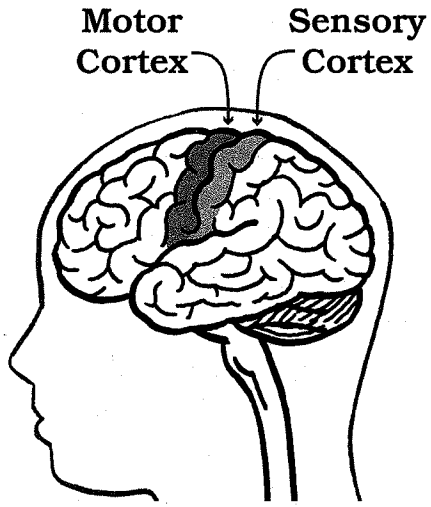
Although Mitchell made phantom limbs an object of legitimate scientific study, this knowledge didn't readily translate into treatments. For most of the twentieth century, in fact, no different than in Mitchell's day, doctors merely fit amputees with prosthetics and, if the phantom pain got bad, plied them with opiates. But in the 1990s phantom research went through a renaissance, as neuroscientists realized that it provides a unique glimpse into the brain's movement centers and especially into brain plasticity.

The brain's primary movement center is the motor cortex, a strip of gray matter that starts near your ears and runs to the top of your head. It sends out the commands that spur the spinal cord to move your muscles. On its own, however, the motor cortex can produce only crude movements, like kicks and lunges. Think of a bucking



bronco—powerful, but lacking grace. Synchronized movements actually arise from two adjacent regions, the premotor cortex and supplementary motor area. In essence, these two regions coordinate simple movements into something more balletic. To change analogies, they play the motor cortex like a piano, pressing different areas in quick succession to produce complex chords and arpeggios of movement—walking, for instance, requires different muscle groups to contract with a precise amount of force at different moments. Toddlers stumble so much in part because their brains still hit false notes.

To execute a complicated movement, the motor areas also need feedback from the muscles at each stage, to ensure that their commands have been carried out properly. Much of this feedback is provided by the somatosensory cortex, the brain's tactile center. You can think about the somatosensory cortex as the motor cortex's twin. Like the motor cortex, it's a thin, vertical strip; they in fact lie right next to each other in the brain, like parallel pieces of bacon. Both strips are also organized the same way, body part by body part; that is, each strip has a hand region, a leg region, a lips region, and so on. In effect, then, the motor cortex and somatosensory cortex each contain a "body map," with each body part having its own territory.

In some ways this body map is straightforward; in other ways it's not. For example, just like on your body, the map's hand region lies right next to the arm region, which lies right next to the shoulder region, and so on. But in other spots, the topography is scrambled. In particular, the hand territory also borders the face territory, even though the hand itself doesn't border the face. Just as randomly, your foot territory nestles against the crotchal region.

The brain's body maps also contain another counterintuitive feature. Despite what you might think, big body parts don't need big patches of gray matter to function. Legs, for instance, although powerful, don't require complicated instructions to jump or kick, and they're not very sensitive to touch, either. As a result, these big burly parts get by with minuscule, Luxemburg-sized territories on the touch

and movement maps. The lips, tongue, and fingers, meanwhile, engage in intricate movements such as speaking and handling tools, and therefore need Siberia-sized tracts of neurons. Some body parts, in other words, are magnified on the maps. (This explains why amputee soldiers felt missing fingers more than missing hands, and missing hands more than missing arms: our brains pay more attention to fine-motor structures.)

With all that in mind, consider what happens when a hand is amputated. First, a huge territory on the brain map goes black. It would be like watching the United States from space at night, with all its patches of sprawling suburban illumination, and seeing the power grid in Chicago fail. The key point, however, is that this spot doesn't stay blank. Because the brain is plastic, adjacent areas can colonize the hand region and use its neurons for their own ends. With a missing hand, it's usually the resource-hungry face territory that encroaches.

This encroachment happens quickly, sometimes within days, and happens over long neural distances, up to an inch. For these reasons scientists suspect that colonization cannot simply involve new neuron tendrils sprouting up and "invading" empty territory. Instead, the colonizer probably fires up preexisting circuits that were lying dormant. Again, the brain has bazillions of neural circuits running every which direction, and some of these tracts happen to start in the face territory and spill over into the adjacent hand region. Most of the chatter on these circuits is irrelevant to the hand, so the hand region mutes them. But when the hand area falls quiet, it loses the ability to resist. The nearby cheek and lip areas suddenly face no opposition and can take over.

Still, as every colonial power in history has learned, occupying a territory is different from assimilating it. Too many "hand circuits" exist to reprogram them all, and the hand territory always retains a vestige of its identity. As a result, the new face circuits and the old hand circuits overlap and intermingle, and both can end up firing simultaneously.

What does this all mean on a higher scale, the scale of perception? It means that for some amputees, touching or moving their faces will summon up sensations in their missing hands. If an amputee strokes his cheek, for instance, he might feel his missing thumb being brushed. If he whistles or chews gum, the index finger twitches. If he pops a chin zit, the pinkie feels the squeeze. Even those people who don't consciously register the dual sensations will still have signals intermixing in the brain. The net result is that face sensations keep stoking the mental memory of the hand and keep stirring the phantom awake.

(Similarly, because the foot and genital territories border each other on the brain map, when the lower leg disappears, the genital spot can take over. Sure enough, some lower-limb amputees feel their phantom feet most insistently during sex. A few even report feeling orgasms quaking all the way down to their phantom tiptoes. And, like striking a bigger tuning fork, this expansion of the orgasmic territory gives them a proportionately greater pleasure.*)

Scientists gained another crucial insight into phantom limbs from a series of almost comically low-tech experiments conducted by a neurologist in Southern California named V. S. Ramachandran. Ramachandran had a patient named D.S. who'd lost his left arm after a motorcycle wreck and had experienced severe phantom cramping ever since. To treat him, Ramachandran took an open-topped cardboard box and mounted a mirror inside. The mirror divided the box's interior into two parts, a left chamber and a right chamber. Ramachandran cut a hole in the box on either side of the mirror and had D.S. slide his right hand into the right chamber. (D.S. also imagined sliding his phantom left hand into the other chamber.) The crucial point is that the reflective surface of the mirror faced right. So when D.S. inserted his hand into the hole and glanced down, it looked like he had two intact hands again.

Ramachandran had D.S. close his eyes and start swinging his hands back and forth symmetrically, like someone conducting the

philharmonic. At first nothing happened. The phantom stayed frozen, mute. D.S. then opened his eyes and repeated the motion while looking in the mirror. That's when the orchestra burst into song. As his hands swayed back and forth, his phantom fingers unfurled for the first time in a decade. His cramps abated, his rigid wrists went loosey-goosey. "My god!" he yelled, and began jumping up and down. "My arm is plugged in again."

Over the next few years many more amputees would share that same glee in Ramachandran's office. The "mirror box" looked hokey, sure. But something about *seeing* a lost limb in motion unfroze the phantom in people's minds. Again, we dedicate loads of brainpower to vision, and we implicitly trust sight over our other senses—seeing is believing. So when the eyes see a limb moving again, the brain believes it can.

Based on this and other insights, scientists like Ramachandran have now sketched out an explanation for why phantoms exist and why they often snarl with pain. Because the brain has a hardwired mental scaffold of the body, it expects to find four full limbs at all times—that's its default setting, and that's why even people born without limbs can experience phantoms. Moreover, the reality of phantoms is reinforced when the brain keeps receiving spurious signals, both from the inflamed stump and especially from any greedy brain territories that colonize an empty neural landscape. All this activity fools the brain into thinking that the hand or leg still exists. So the brain keeps sending motor signals down there, and armless men keep grabbing for their hats in gusty weather.

That explains the sensation. The paralysis and pain arise for different reasons. If the limb was paralyzed before the amputation, the phantom is usually paralyzed afterward, too. But even people who can "move" their phantoms at first often lose that ability later. Remember that the brain, after it sends off a movement command, looks for sensory feedback to confirm that movement took place. Arms that don't exist obviously don't provide this feedback. So,

over time, most people's brains conclude that the phantom is paralyzed.

Pain can get stamped into a phantom limb just like paralysis does, when preamputation aches and pains carry over. But motor commands can also exacerbate the pain. Because an AWOL limb can't respond to motor commands, the brain—which hates being disobeyed—often ratchets them up: a failed command to *squeeze the left hand* gets transformed into *squeeze hard,* then *squeeze harder,* then *squeeze like hell.* This causes pain for two reasons. One, pain signals alert the body that something is wrong, and with this mismatch between motor commands and sensory feedback, there's clearly something amiss here. Second, brutal commands like those were usually accompanied by pain in the past: your brain learned, for instance, that clenching your fist caused your fingernails to gouge your palm. Eventually the hand-clenching circuit and the pain circuit got wired together. As a result, whenever the brain tries to rouse the phantom with a hard squeeze, pain sensors can't help but fire.

The mirror box, however, slits the neural Gordian knot. It resolves the mismatch between the motor and sensory systems, and because the brain literally sees its commands being obeyed, it can stop sending out orders to *squeeze* and *squeeze harder.* In the sudden tranquility, the pain seeps away. To be sure, at first the relief lasts only a few hours before the phantom seizes up again. Not everyone finds relief from mirror therapy, either. But those who do, and who practice with the mirror box, can see profound improvement over time as their brain maps reorganize. In many cases the pain all but disappears. (You can think about this decoupling as the converse of *neurons that fire together wire together.* Here, *neurons out of sync fail to link.*) And in some cases the phantom itself vanishes. After Ramachandran's first patient, D.S., drilled with the mirror box for several weeks, he felt his phantom left arm shrinking inch by inch, "telescoping" up into his shoulder. Finally, just a nub of sensation remained. Ramachandran called this the first successful amputation of a phantom limb.

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After publishing his magnum opus on phantom limbs in 1872, Silas Weir Mitchell went on to a career of such brilliance that one admirer declared him "the most versatile American since Benjamin Franklin." He helped pioneer the study of sleep paralysis, traumatic shock, and object blindness. He also resumed his venom research; conducted some, ahem, personal experiments with hallucinogens such as mescaline; and, most infamously, invented the "rest cure" for psychological disturbances, an outgrowth of his interest in helping Civil War vets return to civilian life.

For men, Mitchell's rest cure consisted of a few weeks of roping cattle and sleeping outdoors in the Dakota Badlands or areas farther west. Mitchell prescribed such a retreat, with plenty of mountain air, for his buddy Walt Whitman in 1878, after tracing the poet's dizziness, headaches, and vomiting to a small stroke. Painter Thomas Eakins also underwent this "West cure," and the regimen supposedly cured the young Teddy Roosevelt of his effeminate voice and foppish mannerisms in the 1880s. (Before this, TR was considered soft, and people compared him to Oscar Wilde.) For women, especially for "hysterics," Mitchell prescribed a different sort of rest cure. It consisted of six to twelve weeks of bed rest in a dark room, along with massages, electrical stimulation of the muscles, a sickening surfeit of fatty foods, and complete isolation (no friends, lovers, letters, or novels). As you can imagine, spirited women resented this. After the birth of her daughter and subsequent postpartum funk, Mitchell basically ordered the writer Charlotte Perkins Gilman to stay in bed and stop making trouble: "live as domestic a life as possible," he said, "never touch pen, brush, or pencil again." She responded by writing "The Yellow Wallpaper," a classic feminist story about a woman driven mad by such treatment. (Virginia Woolf gave Mitchell a similar working over in *Mrs. Dalloway*.) Gilman later mailed a copy of her story to

Mitchell and claimed that he amended his ways because of her, but in reality Mitchell continued to condescend to female patients, especially hysterics. When one hysteric refused his orders to end her rest cure, he threatened, "If you are not out of that bed in five minutes, I'll get into it with you." She held out while he removed his coat and vest, but skedaddled when he unfastened his fly. In another case, with a woman faking a mortal illness, he sent all of his assistants out of the room. When he emerged a minute later, he promised she'd be up in no time. How did he know? He'd set her sheets on fire.

In addition to his medical practice, Mitchell began to study medical history, especially the deep and unsettling synergy between war and medicine. As he well knew, only during combat do doctors and surgeons see enough cases of ghastly things like shattered limbs to become experts on them. Moreover, the Civil War prompted great improvements in patient transport, anesthesia, and hospital hygiene. Mitchell's general observation holds for other wars as well. Modern nursing began with Florence Nightingale in the Crimea, and the Franco-Prussian War proved once and for all the importance of vaccines. Later, the Russo-Japanese War sparked important vision research, and World War I improved the treatment of facial injuries. More recently, Korea, Vietnam, and other conflicts taught surgeons how to reconstruct mangled nerves and veins and reattach severed limbs, thus preventing phantoms from arising in the first place. And the recent wars in Iraq and Afghanistan—where close-quarter explosions left thousands of soldiers with low-level but pervasive neuron damage reminiscent of concussions—will no doubt provide their own innovative remedies. However much suffering they produce in the short term, wars have benefitted medicine profoundly.

Even as his scholarly and scientific reputations were peaking, Mitchell felt more and more drawn to another pursuit—writing. His clinical papers on nervous ailments had always felt dehumanizing: too liable, in their pursuit of general truths, to trample an individual's

story. In contrast, fiction writing let Mitchell capture the nuances of a man's life, and capture the way he experienced something like phantom limbs. Mitchell was actually taking part in a broader literary movement: Balzac, Flaubert, and others also poached on medical work to heighten realism and draw more convincing portraits of suffering. Nevertheless, fiction writing wasn't deemed a respectable hobby for physicians in those days, and Mitchell's friend (and fellow doctor and writer) Oliver Wendell Holmes Sr. advised him to keep his writing on the down low, since patients wouldn't trust a doctor who used them as fodder.

Only in the 1880s, after twenty years of publishing anonymously, did Mitchell come out of the authorial closet. Thereafter his scientific work tapered off, and he began writing almost full-time, eventually publishing two dozen novels. He often saddled his characters with seizures, hysteria, split personalities, and other nervous ailments. And although he wasn't above tossing in a ghost to enliven the plot, he wrote mostly realistic works with an emphasis on moral dilemmas. Teddy Roosevelt declared Mitchell's bestseller *Hugh Wynne: Free Quaker* probably the most interesting novel he'd ever picked up. And toward the end of his life, at age seventy-five, Mitchell finally owned up to writing "The Case of George Dedlow" four decades earlier. Mitchell had taken Dedlow's name from a jeweler's shop in a Philadelphia suburb, mostly because he found it apt ("dead-low") for a double leg amputee. He'd sent the story to a female friend for feedback. Her father, a doctor, read about phantom limbs with fascination, and forwarded it to the editor of *The Atlantic Monthly.* Mitchell claims he forgot about the story until the page proofs and an $85 check arrived in the mail. Regardless, the story's success galvanized him. At that point he hadn't published anything academic about phantom limbs, and without the public outpouring for Dedlow he might never have pushed his fellow doctors to take phantom limbs seriously.*

A friend once noted of Mitchell that "every drop of ink [he wrote] is tinctured with the blood of the Civil War." Even on his deathbed—in January 1914, as the world prepared for a new war in Europe—Mitchell's mind could only drift back to Gettysburg and Turner's Lane. He in fact spent his last, delirious moments on earth conversing with imaginary soldiers in blue and gray, pursuing phantoms to the end.