

CHAMPAGNE FOR THE BLIND

Paul Bach-y-Rita, Champagne for the Blind:
Paul Bach-y-Rita, Neuroscience's Forgotten Genius

By Aviva Hope Rutkin

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B.S. Neuroscience
Union College, 2012

SUBMITTED TO THE DEPARTMENT OF COMPARATIVE MEDIA STUDIES/Writing
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

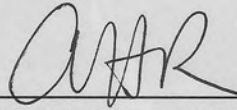
MASTER OF SCIENCE IN SCIENCE WRITING
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SEPTEMBER 2013

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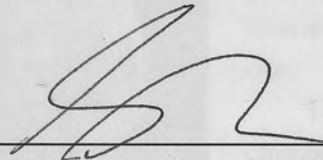
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June 10, 2013

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Submitted to the Department of Comparative Media Studies/Writing
on June 10, 2013 in Partial Fulfillment of the
Requirements for the Degree of Master of Science in
Science Writing

ABSTRACT

Dr. Paul Bach-y-Rita was a visionary neuroscientist and an early pioneer of the theory of neuroplasticity. He is the father of sensory substitution, a field which explores how one sensory modality can be transferred to another. This work culminated in the invention of the Brainport, a device that transmits information through electrodes on the tongue. Bach-y-Rita's company, Wicab, developed two versions of the Brainport. One uses visual information to reveal the sighted world to the blind; another uses body alignment information to help "wobblers" (individuals with vestibular conditions) navigate. The author received exclusive access to Bach-y-Rita's unpublished memoirs. These papers—supplemented by visits to Bach-y-Rita's home in Wisconsin and personal interviews with his family and colleagues—help tell the story of a revolutionary technology that failed to reach the public who needed it.

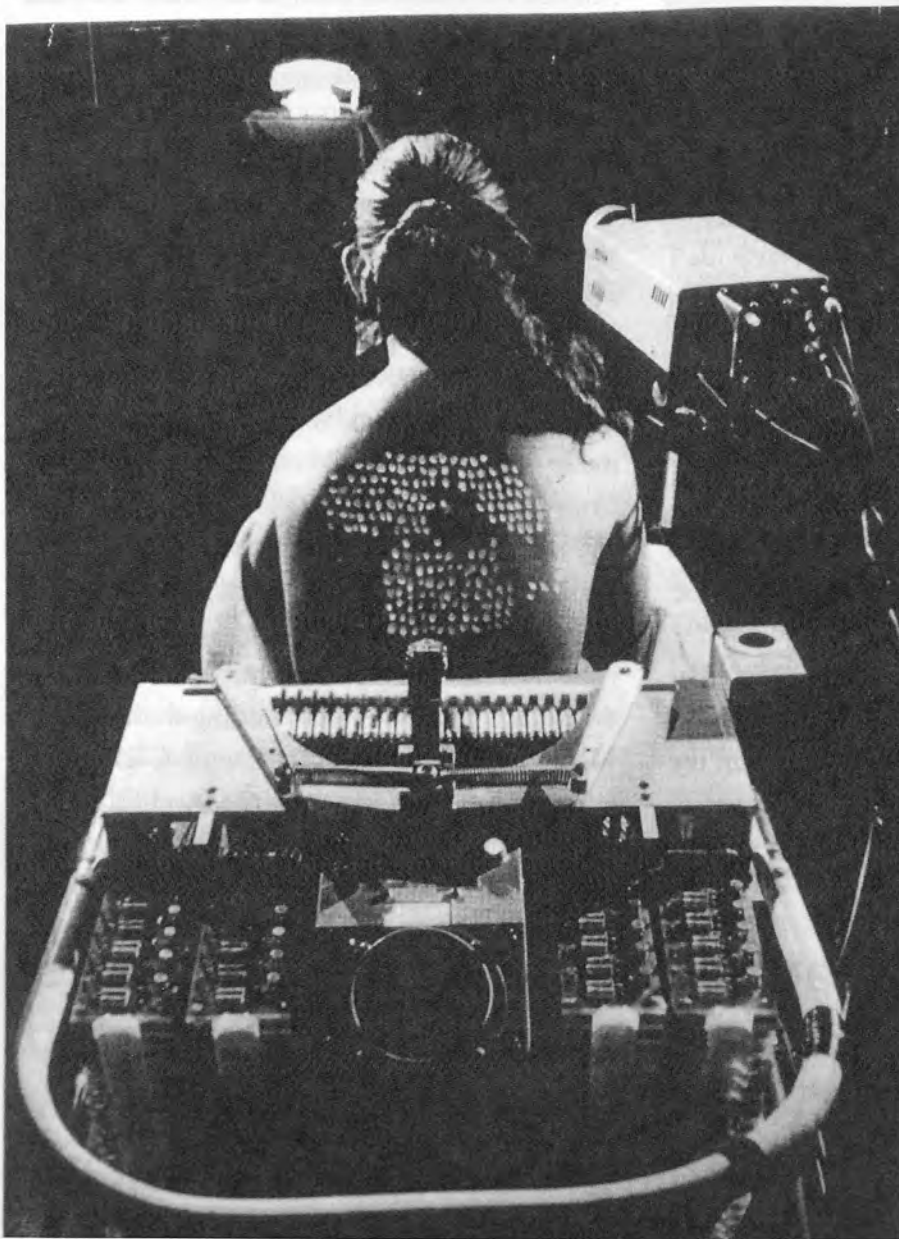
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CHAMPAGNE FOR THE BLIND

Paul Bach-y-Rita, neuroscience's forgotten genius

By Aviva Hope Rutkin

In 1968, researchers invented a revolutionary device allowing blind people to see using their skin. This is the story behind the man who pioneered this technology -- and the reason that you've probably never heard of him.



Bach-y-Rita's Tactile Vision Substitution Device, invented in 1968.

You don't see with the eyes. The neuroscientist Paul Bach-y-Rita repeated that phrase often. He was obsessed with the idea that the brain is capable of change and thought this power could be used to make one sense replace another. Sound translated into visual images, for example. Vision transformed into touch.

You don't see with the eyes, Bach-y-Rita repeated to his astonished listeners, in scientific papers, in lecture halls around the world. You see with the brain. Just give the brain information and it will figure it out.

The notion of a changing brain, known as sensory substitution, was long considered borderline heretical by the scientific commu-

nity. That didn't dissuade Bach-y-Rita from believing he was right. From 1965 onward, he oversaw the development of a string of curious machines designed to help people harness the power of their senses. His last such invention, the Brainport, was also his greatest. It was small and simple: a camera built into a pair of ordinary sunglasses, attached to a thin white strip studded with electrodes. The strip rested like a lollipop on the tongue, where it buzzed and pulsed in the shape of the world around the user. Sight turned into electric tingles.

"I have never felt this before," one blind test subject told *The London Times* in 2001. "I can perceive something out there."

The Brainport made headlines for a brief period in the early 2000s. Employees at Bach-y-Rita's company, Wicab (*wee-kob*), boldly predicted that the device would be on the market at any moment; that there were dozens of possible therapeutic applications; and that "everybody who has a sight impairment will be using it."

I first ran across Bach-y-Rita's name while researching sensory substitution in a Boston library. He is cited in nearly every paper on the topic, crowned by more than one researcher as the father of the field. Despite this, Bach-y-Rita

now appears to have all but disappeared from public memory. News about the Brainport peters out around the same time as his death in 2006, and his name barely appears on Wicab's website. Now, when I asked the University of Wisconsin-Madison (UW), where he worked for the last 23 years of his life, about his files, they emailed me a scan of a single obituary. The text made it clear that not everyone had forgotten about him: former colleague and ophthalmologist Arthur Janpolsky painted Bach-y-Rita as a rare visionary. "Ideas sparkling in every direction from his brain, unique and innovative, far ahead of his time," he said. "And the seeds he planted in many scientific gardens will benefit scores of people now, and in the future, whom he, nor we, will never know."

Perhaps. But similar proclamations were made in Bach-y-Rita's life, and they never came true.

Last January, I flew out to the heartland and drove up to Bach-y-Rita's old home in a rented Ford Fiesta. He lived in a small house set back from the street, atop a hill just outside downtown Madison. Still residing there is Bach-y-Rita's short and dark-haired widow, Esther, as well as his youngest daughter, Andrea, Andrea's boyfriend, three cats, and one tiny,

"Bach-y-Rita launched a revolution in science that he did not live to see completed. His is a legacy whose significance is only now beginning to be noticed but will be remembered for centuries to come."

Stephen Kercel, former Oak Ridge National Laboratory engineer

trembling, gray poodle.

If I hadn't already known that Bach-y-Rita was gone, I might have thought he was still living there too. His papers are everywhere. They pile behind the living room couch and atop the family piano and in plastic bins in the basement and on the shelves of back rooms. Cats stretch lazily on the unfiled stacks whenever Esther's back is turned. His CDs still sit in a wicker basket in the dining room, and colorful posters from his conferences still adorn the walls. He figures prominently in nearly every family photo, looking exactly the part of a mad scientist: wild Einsteinesque hair, slight stature stooped from reading, a mischievous and toothy grin.

At night, I slept in the former bedroom of one of Bach-y-Rita's four daughters. Each morning, I hunkered down in the sun-lit den. The house has an open floor plan, with big archways instead of doors, and from my seat I could see Esther bustling about in search of her husband's papers. She brought over newspaper clippings, scientific articles, Betamax tapes, books in French and Spanish, photocopies upon photocopies of the same old letter. There were three flash drives crammed full of files and huge photo albums with padded white covers. Esther and I spent one afternoon resurrecting an 80s microcassette player, coaxing it to play back a tinny version of Bach-y-Rita's voice.

Prized among the findings is a green hanging folder, full of typed essays numbered in Esther's hand. These are the unfinished chapters from Bach-y-Rita's unpublished memoirs, a side project he worked on in the last few years before his death. I am the first person outside of the Bach-y-Rita family to read this stack of pages.



Paul Bach-y-Rita, in his office at UW.

They are the closest thing to a conversation he and I will ever have.

"I always meant to do something with those," Esther tells me. "But it was too painful."

There are almost three dozen chapters in all, in various states of polish, running anywhere from ten pages to three sentences long. They range from nostalgic stories about Bach-y-Rita's childhood to serious treatises on technical subjects. In 'The Ontogeny of a Scientist,' he laments the amount of time doctors waste in graduate training. In 'Scorpions in Tilzapotla,' he recalls how the husband of a woman in labor once held a gun to his head. He discusses his research, his struggles with colleagues, and his father Pedro's radical upbringing in Spain. Clipped to the back of one chapter about youth baseball is a pitch letter to Woody Allen, encouraging the director to use the piece as inspiration for a new movie. (Allen never wrote back.)

Bach-y-Rita appears to have wrestled most with the memoir's opening chapter. There are

four different drafts, each substantially different. He first likens the brain to a computer, then changes it to a monarch butterfly, then to a vast landscape of rivers and forests. He tries to summarize his life in a few grand strokes.

"This is the story of a 40 year personal search for the brain's treasures," he wrote in one version. "Like all sagas, this long journey is full of twists and turns, successes and failures, alliances formed and broken, friendships and bitter rivalries, support and sabotage. There is no science without scientists and the people around them, and the influence of the world and times in which they live their very human lives."

These beginning drafts are one of the only places where I can sense any doubt in Bach-y-Rita. He is attempting to make sense of the patterns in his life, to find lessons in the places where he did or did not triumph.

My favorite of all his opening lines were one of the last he wrote, just a few months after his cancer diagnosis in 2004.

"This is an adventure story."

The Plastic Brain

The brain, like a rich landscape, contains many distinct locations. Most of these are intended to fulfill a particular purpose: Here is the spot that controls how we talk, there is the place responsible for sensation in the fingertips. Neuroplasticity means that we can tweak this invisible map—shift the borders between one area and another, perhaps, or redirect a particular avenue—in response to changes in our body and the world around us.

Though the theory of neuroplasticity is widely accepted now, it was long derided and dismissed by the scientific community. Up until a few decades ago, most scientists believed that the brain's map was fixed, a theory known as localization. If one area was damaged, the thinking went, then the functions that area was responsible for were probably lost forever.

Localization dates all the way back to the 1600s, when the philosopher Descartes first speculated that he had found the human soul. The pineal gland, he announced in an essay, was "where the seat of imagination and common sense" resided. (We now know the pineal gland as a seat of hormone production.) The brain was largely a mystery in Descartes's time, and it remained that way for centuries afterward. Some supposed that our thoughts were located in the heart rather than in the head. Others believed that the brain's powers were decentralized and disorganized, with information stored in the manner of books tossed thoughtlessly onto a shelf.

It took centuries, but, slowly, the mystery began to unravel. In the early 1800s, French physiologist Jean Pierre Flourens was commissioned by Napoleon to investigate the inner workings of the brain. Flourens set about systematically destroying different parts of pigeons' brains. He described how the loss of each section would affect the animal's behavior. For example, removing the cerebellum in the back of the skull would merely make the pigeon uncoordinated, while removing the part connecting the brain to the spinal cord would result in the bird's death.

Flourens's findings seemed to buoy the belief that different sections of the brain were re-

served for specific tasks. However, not all of Flourens's observations pointed to localization. Over the years that he observed his pigeons (and later, dogs), he noticed that some animals started to recover their lost skills without actually growing back the brain areas that he had destroyed. This led Flourens to conclude that, although different parts of the brain had specific characteristics and operated on their own, they all belonged to a single system that was sensitive to changes throughout.

But Flourens's work supporting a more fluid view of the brain, and the few other experiments that corroborated him, were later eclipsed by a study from another French scientist. Pierre Paul Broca, a physician in Paris, was treating a curious patient who had lost all of his powers of speech over the last few decades of his life. By the end, the patient could only utter a single word: "tan." After he died, Broca performed an autopsy and found that the damage in his brain was mostly isolated to a single small lobe on the left side of the head. Soon afterward, Broca uncovered six other people who had only been able to utter a few nonsense words, all with significant damage in the same spot. He concluded that this area must be the language center of the brain.

Broca's discovery prompted researchers to catalogue other kinds of brain damage in an attempt to mirror his results. One research team in Germany recorded which muscles twitched when different areas of a live dog's brain were electrically stimulated. Elsewhere, anatomists carefully mapped the distinct grooves in the human brain's surface, an effort that culminated in a pivotal 1909 paper dividing the organ into 52 distinct regions.

By the middle of the twentieth century, localization was so taken for granted that it molded scientists' expectations how the brain worked. The medical community now assumed that it would be difficult, if not impossible, for an adult brain to recover skills that it had lost. They considered severe brain damage cases hopeless, beyond the reach of rehabilitation. What was the point of working with a patient who could never recover?

Growing Up

Of the three children in the Bach-y-Rita family, Paul was by far the most difficult.

He grew up in a quiet working-class neighborhood in the upper Bronx. Bach-y-Rita's father, Pedro, was a Catalan poet who taught classes at City College in New York. His mother, Anne was the daughter of Jewish-Ukrainian immigrants. Bach-y-Rita was born in the spring of 1934, preceded by his older sister, Joan, and followed by his younger brother, George.

Paul was small but scrappy, incapable of backing down from a fight. He was once sent home from school in the sixth grade for arguing with his teacher over how to properly address an envelope. He recalled another winter when he wanted to sleep on the snowy back porch, too stubborn to admit to his parents that he was cold. Anne despaired over her son's rebellious streak.

"Mama had to learn to deal with my rejection of authority," Bach-y-Rita later wrote in his memoirs. "It was not a matter of love. I loved her very much. It is just that I could never stand

being told what to do, and I was willing to pay the price of my independence.”

Pedro loved and encouraged his son's brash behavior. The scholar-poet was also a lifelong activist who had helped to organize the first major student strike in the United States, in protest of his department chairman's anti-Semitism. At the dinner table each night, Pedro spurred his children to debate fiercely about everything from civil rights issues to the latest news in baseball. In Paul's memoirs, he credited his father as “the strongest influence on the development of my mind.”

When Paul was fifteen, the entire family moved to Mexico City. There, Paul completed a pre-law degree at the local college in two years, and then moved on immediately to medical school at the Universidad Nacional Autonoma de Mexico. The experience was grueling. Bach-y-Rita's limited science background was poor

preparation for the school's notoriously brutal first-year classes, which were taught entirely in his second language of Spanish. He was living on his own for the first time and struggled with dysentery, a difficult roommate, and the restless tedium of graduate school life at only seventeen.

So he dropped out. Bach-y-Rita spent the next year hitchhiking across the United States, supporting himself with whatever odd jobs he could find. He bused tables in Florida, sold vacuums door-to-door in Texas, and worked on a shrimping boat in the Gulf of Mexico—an experience that left him violently seasick. He spent six weeks working on a factory bench at the Boeing Aircraft Company. In Miami Beach, he taught anatomy to veterans who were training in the art of massage.

Throughout this time, Bach-y-Rita's brief stint in medical school was never far from his mind. Wherever he went, he carried his tattered



From left to right: George, Joan, and Paul Bach-y-Rita, circa 1940.

human anatomy textbook, taking it out to read "when things were quiet." And when the following fall came around, he returned to Mexico City, ready to re-enroll as a medical student.

Once there, Bach-y-Rita registered in a course taught by Raúl Hernández Peón, a brilliant young physiologist fresh off a year at Yale studying how the body attends to different sensory signals. The class turned out to be "the defining experience" of Bach-y-Rita's professional life. Peón recognized something promising in his energetic student and arranged for Bach-y-Rita to spend the following summer assisting in neuron network research at the University of California at Los Angeles. That was the summer Bach-y-Rita fell in love with the study of what he called "our most noble, wondrous, and magnificent possession," the brain. The UCLA laboratory was a lively place, "bubbling with ferment" and brimming with interdisciplinary scientists from around the globe. Bach-y-Rita returned every summer until graduation. By the time he received his medical degree in 1959, he had co-authored a total of five scientific publications in English and Spanish.

"I was completely seduced by the attractions of brain science," he said, "and never seriously considered doing anything else."

After graduation, Bach-y-Rita returned to wandering the world, this time as a promising scientist instead of a penniless teenager. He volunteered as a village doctor in rural Mexico, studied brain anatomy in Paris, and spent a year as a post-doctoral fellow in southern Germany. He also met and married his first wife, Eileen Morganstern, with whom he would have his first two children.

Bach-y-Rita hopped from one successful

project to another, curating a reputation as a specialist in eye muscles and nerves. Though he enjoyed his work, he was not satisfied by it. His mind drifted. In particular, Bach-y-Rita found himself drawn to speculation that certain brain cells could handle more than one kind of sensory information. He daydreamed about fantastical devices that could transmit the visual world to blind people using some sense other than sight.

"I was convinced that that identity of sensory information, the real message carried by a particular sensory system, could be modified by training and experience," he wrote. "The main problem seemed to be: how can visual information be carried to the brain when the visual system is lost?"

Bach-y-Rita looked for signs that such a project might be possible and uncovered a few studies that suggested pictures could be represented through touch. The most promising was from an aircraft engineer named Tyler Gilb. During World War II, Gilb had tried to build a machine that represented the world in a grid of pressure points, filling his beach house with unsuccessful prototypes. However, Gilb was ultimately forced to abandon the scheme, because supplies were scarce and his employers at the Lockheed Aircraft Company disapproved of the project.

When Bach-y-Rita returned to California in 1963 to work as a researcher at Smith Kettlewell Eye Research Institute, he began to search for a suitable collaborator. Carter Collins, an engineer and a biophysicist at the institute, was intrigued by the young neuroscientist's bizarre proposal. Before long, the two were meeting up after-hours to discuss how they might build a

machine that turned images into electrical stimulation on the skin.

Their colleagues at Smith Kettlewell were not impressed. "We were considered crazy dreamers," Bach-y-Rita wrote. Again and again, their applications for funding were rejected. They labored for three years without any money, forced to relegate work on the project to their free nights and weekends. Equipment—a surplus dentist's chair, an old television camera, a fish-eye lens—was scrounged from the junk piles of other laboratories and gathered up in a spare room. They convinced the hospital to hire a local navy engineer, who they often spirited away from official duties to help Frankenstein together the disparate parts.

Father and Son

Around the same time that Bach-y-Rita graduated from medical school, his father suffered a serious stroke. Pedro was living alone in New York City when it happened, his children all grown up and his wife already gone. It fell to the family's youngest, George, to pick Pedro up from the hospital. When George arrived, he found his father slobbering in a wheelchair and paralyzed along his right side, unable even to speak.

The doctors gave Pedro a mere six weeks of rehabilitation treatment before discharging him. That's it, they told George. You should take your father home, or put him in an institution where they can take care of him.

George was a medical student at the time, enrolled in the same program at UAM that Paul had just completed. He, too, had studied the lo-

calizationist brain models and been taught that a neuron lost was lost forever. Still, he had trouble accepting that there was nothing more to be done. Though Pedro was trapped in a malfunctioning body, George sensed that, inside, his father's intellect was still intact. He thought about his former kindergarten teacher, a smart and thoughtful woman who had also recently had a stroke. The doctors had given up on her, too. Then she had died.

That was the lesson George took away: If you gave up, then you died.

Over the 2,000 mile drive back to his house in Mexico City, George resolved to try to rehabilitate his father. Without any guidance, he decided to start from the beginning. Like a baby, Pedro learned how to crawl again, wearing kneepads to protect himself from the tiles. He dragged his body around from room to room and practiced scooping up coins that George had thrown on the floor.

"It seemed positively cruel," Paul Bach-y-Rita wrote, "except for their bond of love and respect."

After a few months of this, Pedro found that he was able to walk upright if he struggled along the wall for support. George and Pedro then found ordinary household tasks for Pedro to practice while his son was out at class during the day. He buttoned his shirts and washed dirty dishes, running his bad right hand around and around the inside of a cooking pot. He typed with the same bad hand rather than write with his able left, patiently dropping his middle finger onto the typewriter's keys. Pedro spent nearly five hours each day on these simple tasks.

To his and George's amazement, it seemed to work. By the end of a year, Pedro had recov-



Autopsy view of Pedro Bach-y-Rita's brain.

ered enough to go back to teaching. By the next, he was strong enough to live a normal, independent life. Five years after the stroke, the only sign that Pedro had ever been sick was some slight discomfort in cold weather.

The supposedly hopeless patient left George's house, remarried, and moved to California, where he continued to practice his exercises every day. When he finally passed away in 1965, it was from a heart attack sustained while hiking up a mountain Colombia, a remarkable accomplishment for a man who had been condemned to life in a wheelchair just six years earlier.

The Bach-y-Rita children decided to grant permission for an autopsy. Though dramatic recoveries like Pedro's were not unheard-of, the opportunity to study the brains of such patients was rare. Pedro might make an excellent case

study for neuroscientists. During the autopsy, the neuropathologist in charge of Pedro's case called Paul Bach-y-Rita and asked him to visit her office.

"When I got there," Bach-y-Rita wrote, "I found Dad's brain cut into slices."

A chunk of Pedro's left medulla oblongata—a section responsible for involuntary muscle movements—was shrunken and gray, with no usable tissue left. There was a huge hole in his brainstem, and the basis pontis, another area involved in motion, was riddled with pits of decay. Pathways that had once carried high-speed messages away from the brain had been stripped of most of the fatty neurons needed to pass those messages along. In short, Pedro's brain didn't look like it belonged to a man with command over his body, let alone someone who was capable of hiking up anything.

The neuropathologist was visibly excited by the implications, but Bach-y-Rita was repulsed by the sight of his father's brain carved up on a tray. "I was too shocked to talk, but [I] listened to her exclaim that she had never seen anything like it, that there was a tremendous amount of destruction from the stroke and no way to explain the recovery," he said.

She said that she wanted to publish the case and asked Bach-y-Rita to be a co-author. He refused and left the room.

But he could not stop thinking about it.

"How could he have recovered so much?" Bach-y-Rita asked himself. "I had heard about miraculous cures, but here there was clear evidence of recovery in spite of incredible damage to an aged brain with poor circulation, confirmed by autopsy. If he could recover, why didn't others recover?"

Touch into Sight

Meanwhile, Bach-y-Rita and Collins continued to work on their vision device. By 1967—two years after Pedro's death—their first prototype was finally complete.

A television camera, too heavy for any one person to hold up for a long time, stood on a large tripod in the center of the room. Its live video feed traveled along electric wires to a metal grid fixed to the back of the dentist's chair. The grid, which was about the size of a piece of notebook paper, was divided up into 400 identical vibrating tips, each one representing a part of the image captured by the camera. Bach-y-Rita compared the grid to the way a newspaper photograph is made up of hundreds of little gray dots.

To Bach-y-Rita, the machine seemed cumbersome and awkward, but it was enough to finally convince the National Institute of Health to award them \$2,000 for experimentation with real subjects. This amount, equal to a little less than \$15,000 today, was far less than any of Bach-y-Rita's other grants, but it was still enough to move the project forward. The two scientists recruited dozens of people, both sighted and not, to try the machine. Many were local college students who had been blind since birth. They sat shirtless in the chair, manipulating the camera with hand cranks to focus on different parts of the room. As the grid vibrated in the response to the camera's picture, the users could feel the tips create tiny ripples on the skin of their back.

They started with a simple task: try to distinguish a straight line from a curved one. Over the course of a few hours of practice, the users

moved up from the lines to identifying basic shapes, and then on to recognizing household objects like a telephone or a coffee mug.

At first, it might take as long as eight minutes for users to correctly identify an object. This soon sped up to a matter of seconds. Then subjects became comfortable describing things they had never seen before. When, once, a scientist held his hand up in the front of the camera, the user described it as "an object like the sun, with rays coming out of it." Then he held up his own hand, fingers splayed, to illustrate what he meant.

Once the subjects had mastered 25 individual objects, they graduated to describing the entire laboratory. Bach-y-Rita and Collins were amazed to find that, by the end of several dozen hours of training, an experienced user could depict the room in fine detail, including who was there that day and what they were doing. One subject once confidently confirmed the identity of another girl in the room. "She is wearing her hair down today, and does not have her glasses on," she said. "Her mouth is open, and she is moving her right hand from her left side to the back of her head."

Their results were published in *Nature* in 1969. Bach-y-Rita and Collins's invention, named the Tactile Vision Substitution System (TVSS), was like something out of a science fiction movie: a machine that turned touch into sight. Media coverage was breathless, even triumphant.

"After 5,000 years or more of investigation, the best that science has been able to do for the blind has been to provide them with a long stick, a trained dog and the difficult Braille alphabet," read one account in the *Oakland Sun-*



Smith Kettlewell scientists (Paul Bach-y-Rita at right) pose with a seated TVSS test subject.

day Tribune. “But now there is a chance, a good chance, that the world of the blind can be vastly extended. They may be able to follow the motions of people in the room, navigate down a street unaided and even learn to read print.”

For several years, Bach-y-Rita and Collins continued tinkering. They developed heavy but portable versions that could be worn while walking around, or strapped to the inside of a wheelchair. They also began exploring ways to improve the machine’s resolution, which was limited by the fact that the grid’s tips couldn’t be placed any closer together. By 1976, Collins had told *Newsweek* that a stationary version of the TVSS would be available within two years.

Privately, Bach-y-Rita saw the TVSS as even more than a tool for the blind. The neural systems of people using the device were changing,

Bach-y-Rita thought to himself, as they learned to respond to the TVSS’s vibrations. Just as Pedro’s brain must have adjusted to account for the stroke’s massive damage, so too were the brains of the TVSS users remapping to handle information in a new way.

“If a subject without functioning eyes can perceive detailed information in space, correctly localize it subjectively, and respond to it in a manner comparable to the response of a normally sighted person, I feel justified in applying the term ‘vision,’” Bach-y-Rita wrote. One scientist who supported Bach-y-Rita’s work likened seeing with the TVSS to being color-blind, or having only one eye—just because one’s sight was limited didn’t mean it wasn’t authentic.

The idea that the TVSS endowed its users with vision was plenty bold, but Bach-y-Rita

“If I'm looking at you, the image of you doesn't get beyond my retina... From there to the brain to the rest of the brain, it's pulses. **Pulses along nerves.** Those pulses aren't any different from the pulses along the big toe. It's [the] information that [they carry], and the frequency and the pattern of pulses. **If you could train the brain to extract that kind of information, then you don't need the eye to see.”**

Paul Bach-y-Rita, in a 2003 interview with PBS

began to go even further. It was plasticity, he asserted. The brain could and was changing itself. That was what had happened in the brains of the TVSS's blind users; that was what had happened in the brain of his father. Plasticity was a real phenomenon. Neuroscientists had it wrong.

The theory began to take more and more pride of place in Bach-y-Rita's scientific papers and conference presentations. The mere use of the word cost him dearly. One paper, he recalled, was rejected six times for including it in the title. These rebukes perplexed Bach-y-Rita, who assumed that his conclusions were obvious. He argued that neuroscientists were afraid or incapable of thinking critically about the big picture, and that, as a result, they had relegated speculation on the brain to "the ignorant, the foolhardy, the philosophers and the aging scientists."

For several years, Bach-y-Rita tried to find collaborators who would be interested in exploring clinical applications of the TVSS, but to no avail. The machine was still radical and strange and uncertain, and most scientists were wary of putting too much faith into it. Bach-y-Rita grew frustrated of "working with clinicians who mouthed an interest in progress but preferred to do things their own way." Meanwhile, at Smith Kettlewell, he was urged to ditch the project altogether. Rehabilitation is a less serious branch of neuroscience, one European colleague explained, reserved for those scientists who couldn't cut it in the upper echelons of research. A former mentor told Bach-y-Rita to stop wasting time with that "adult toy."

He thought back again to those bare slices of his father's brain.

"I was in the wrong field," he concluded. "What I could do for Dad and his memory was to extend to others the possibility to recover."

So, in 1979, Bach-y-Rita hit the reset button his life. He left his full-time job at Smith Kettlewell, handing over more than a million dollars in research grants to his fellow scientists. By now, Bach-y-Rita's first marriage had already fallen apart. He had left Eileen for Esther, a beautiful graduate student seventeen years his junior whom he had met while delivering a lecture in Mexico. They lived together in the pool house in his brother George's backyard.

Four days a week, Bach-y-Rita commuted to San Jose, where he had enrolled in a second residency in rehabilitation at Santa Clara Valley Medical Center. The long drives back and forth gave him migraines, and his fellow students, most of them more than a decade younger, half-jokingly referred to him as "the world's oldest resident." On Thursdays he returned to Smith Kettlewell, where his former colleagues whispered behind his back.

Bach-y-Rita paid them no attention. He had bigger questions on his mind.

The Brainport

In 1983, shortly after he had finished his residency, the University of Wisconsin-Madison invited Bach-y-Rita to come lead its new neurorehabilitation department. Though Bach-y-Rita's theories might have been too radical for Smith Kettlewell, there was a subset of the neuroscience community who found his work worth further exploration.

For Bach-y-Rita, it was an opportunity to

focus on proving his theories about the brain. He set up shop in a small set of rooms at the university's medical school and hired men who seemed to share his vision. One of these was Mitchell Tyler, a biomedical engineer whose wife had studied under Bach-y-Rita for several years. Another was a mild-mannered engineering student named Kurt Kaczmarek, who had completed his graduate degree under Bach-y-Rita's direction. Their shared space was a cramped jumble of journals and electrical equipment and makeshift workspaces.

In Wisconsin, Bach-y-Rita developed a reputation for being intensely prolific, dashing off grants and papers at a speed that exhausted his colleagues. He investigated skin's precise sensitivity to changes in vibration; observed the effect of a hopeful outlook on recovering stroke victims; and pored over possible microbiological explanations for how the brain could change late in life. He was especially intrigued by non-synaptic diffusion neurotransmission, a fringe theory that brain chemicals might sometimes spread away from their intended destinations to affect other neurons.

All of these projects returned again and again to plasticity—the same unwavering arguments from research paper to conference lecture to book. He combed back through the archives of neuroscience research in search of early studies that might corroborate his hunches, becoming particularly intrigued by Flourens. He argued that it didn't matter how sensory information entered the body, so long as brain was trained how to use it. He held up sign language and Braille as examples of rudimentary sensory substitution systems. Now that the initial sting of his father's death had passed, he also in-

cluded the surprising autopsy report in his arguments. Bach-y-Rita compared Pedro to the famous actress Patricia O'Neal, who had also recovered from a serious brain injury after years of intensive physical therapy.

Still, progress was slow, and he butted heads with the dean of the medical school over the direction of the neurorehabilitation department. Bach-y-Rita wrote later that he'd been subject to "personal threats, harassment of me and my students, attempts to confiscate my equipment, and unannounced cutting off of my laboratory data lines."

Throughout it all, he kept returning to the TVSS. He thought about it in the mornings as he jogged around his neighborhood. He thought about it in the evenings while he worked in the garden behind his house, weeding and pondering until he fell asleep in the grass.

Bach-y-Rita was obsessed with finding a way to improve that early technology, to develop a sensory substitution device that was practical enough for everyday use. Over more than a decade, his laboratory produced numerous spinoffs, searching for the version that was just right. One device stimulated the abdomen rather than the back; another was designed to fit over the hand like a glove. Bach-y-Rita imagined that a successful adaptation of the TVSS could usher in a new era of assistive sensory devices.

"Technology will never supplant the brain, but technology in the service of the brain offers incredible power and opportunities," he wrote.

One of these spinoffs was the haptic electro-tactile display, essentially a shrunken TVSS. This device was the size and shape of a gray

metal shoebox, with a small grid no larger than a penny on one side. It was designed to work with fingertips, which are more sensitive than skin on the stomach or back. However, the fingertips were not quite sensitive enough, and the machine still required a lot of power to be effective. Plus, many subjects' fingers would become sweaty after only half an hour or so, desensitizing users to the display.

Then, one day in 1995, Bach-y-Rita was struck by inspiration.

It was near the tail end of a record-hot summer in Wisconsin. Bach-y-Rita burst into the laboratory, grinning from ear to ear, and found Tyler and Kaczmarek at the central table, tinkering with the haptic display.

We should use the tongue, he said.

It was so elegant, Bach-y-Rita continued, so simple. The tongue was an exquisitely sensitive organ, far easier to stimulate than the thick protective skin of the fingers. He suspected that saliva would prove to be a benefit rather than an obstacle, boosting the electric signal as it traveled from machine to mouth. Maybe they could build something like a retainer that people could wear while walking the streets of the city, a visual aid far less obtrusive than a cane or a guide dog.

While Bach-y-Rita's enthusiasm ran on ahead, Tyler and Kaczmarek were less than impressed. It's far too daunting to build something that can operate around saliva, they told him. Besides, the lab was already wrapped up in perfecting the existing machine. The two men spent two years putting Bach-y-Rita's idea off, suggesting any number of reasons not to go forward with such a strange notion.

When, in 1997, Kaczmarek and Tyler fi-

nally gave in, it only took a few weeks of tweaking to adjust the display to Bach-y-Rita's specifications. They programmed the device to flash a few simple shapes like a circle, triangle, and square, and inspected it closely to ensure that it was tough enough to handle the flow of saliva. Tyler, feeling very nervous, also decided to scale the electrodes back to less than one-twentieth of their original power, in deference to the keen sensitivity of the tongue.

They placed the device in the middle of the laboratory. With Bach-y-Rita watching, Kaczmarek leaned over and licked the display's steel square.

The little electrodes fizzled against his tongue sharply, but the sensation was more pleasant than painful. As they flashed in different arrangements, Kaczmarek found that he could distinguish one shape from another. It was a curious sensation—one that, later, he and others would liken to drinking a kind of electric champagne.

In that moment, the laboratory was electrified too. They knew they had something unusual on their hands, something much bigger than anything Bach-y-Rita had created before. They called it the Tongue Placed Tactile Output Device.

Within a year, the laboratory had filed a patent, and Bach-y-Rita and Tyler had started their own company. They named it Wicab, Esther's maiden name and a Mayan word that means "lover of honey." She became the nominal president of the company, Bach-y-Rita the chairman of the board.

Neither Bach-y-Rita nor his colleagues had any experience running a company. They were scientists through and through, fascinated by

careful experimentation and accustomed to the slow pace of university research. Their tendency was to stay in the brainstorming stage, and continue finessing the machine's fine details. They didn't even know how to write a business plan.

'The Blind Will See'

In their new official guise as the heads of a company, Bach-y-Rita and Tyler began to search for funding. Many potential investors were deeply skeptical. Here were a bunch of scientists not only arguing passionately that blind people capable of vision, but claiming that all they had to do was put some kind of electrical retainer in their mouth and pay attention to the pulses on their tongue. It sounded like something straight out of Star Trek.

The government finally gave the company its first payday. The Defense Advanced Research Projects Agency, an arm of the Department of Defense more commonly known as DARPA, asked Wicab to modify the mouthpiece so that it could be used as an underwater navigation system for Navy SEALs. Grants like this one gave the scientists the time to start working out the kinks in the vision device.

Schemes for a new, better version formed quickly. It would have to be smaller, the kind of device someone could comfortably carry in a purse. There had to be some kind of built-in camera, constantly streaming information from the outside world. The display would have to be redesigned to be less intense on the tongue's sensitive center and more intense on the duller edges. And they wanted to combine all this into something "cosmetically pleasing"—that is, a ma-

chine that people wouldn't be embarrassed to wear in public.

After Erik Weihenmayer heard about the company's research in 2003, his father reached out to Bach-y-Rita and asked if they could come try the device. At the age of 13, Weihenmayer had lost his sight to a degenerative retinal disease that destroyed both of his optic nerves. Despite this, he had built a successful career as a mountain climber, even summiting Everest in 2001.

Bach-y-Rita's team videotaped Weihenmayer's first visit to the lab. He tested the prototype, then still the size of a shoebox, at a long table covered in black cloth. Sucking hard on the strip, he seemed taken aback by the strength of the electric shock, but soon jumped into the training exercises. He slowly passed a C-shaped piece of paper back and forth in front of his face; reached out to touch white felt letters on a black board; and caught a hard white ball each time the trainer rolled to him from the other side of the table. All the while, Bach-y-Rita stood behind Weihenmayer, beaming.

After less than two hours with the device, Weihenmayer felt comfortable enough to try walking with it. The scientists followed him into the corridor outside the laboratory, carrying the laptop and wires to which the device was still attached. They stood behind and watched as Weihenmayer, strip in mouth, turned his head to look this way and that. Then, suddenly, he reached out and touched an office door.

"Oh wow," he said. "I felt the depth of that little tiny nothing."

Weihenmayer shuffled slowly down the hall. When someone warned him that he was in danger of running into the cameraman, he

laughed.

"Okay, I was wondering. I was seeing you there," he said.

Even Bach-y-Rita, standing at the back, was speechless for a moment.

Meanwhile, the scientists wondered what other kinds of patients could find use for their device. Though their stated goal was to build a system for the blind, they let their imaginations run wild. They spent hours sitting around a table in the lab, spit-balling ideas for new designs. Pacifiers for blind babies. Special sensory gloves for astronauts. Sex toys for people with spinal cord injuries.

"This approach may also have applications to deaf persons, persons with high quadriplegia or limb prostheses, and for augmented communications systems such as in aviation, perception in dark environments, robotics, and underwater

exploration," Bach-y-Rita wrote in 1998 in one of their first papers about the device.

The most promising of these spin-offs involved not the eyes, but the ears. Tyler came up the idea in early 2000 after spending a week at home sick with a bad ear infection. He finally decided to try leaving the house, fighting vertigo and nausea to board a city bus. On the way to work, the bus skidded on ice, and Tyler had a terrible feeling of tumbling through space. He told Bach-y-Rita about his experience the moment he arrived at the lab.

Though Tyler's condition was temporary, they knew there were those who weren't so lucky. People with balance disorders, sometimes known as "wobblers," suffer from irreversible damage in the small canals in their ears that are responsible for managing our sense of where we are in space. If the canals are damaged, then it



Erik Weihenmayer, during his test session with the Brainport, catches a ball rolling toward him.

can become very difficult to walk or even stand. With these individuals in mind, Bach-y-Rita's team began designing a different version of the Brainport, one that would respond to the alignment of the user's body rather than the visual world.

Through the scientist grapevine, Bach-y-Rita discovered the perfect subject to test their idea: a woman named Cheryl Schiltz. Schiltz had been a wobbler for five years, ever since taking an antibiotic called gentamicin to treat an unrelated condition. By the time she learned that gentamicin had possibly dangerous side effects, it was too late. The medicine had destroyed her sense of balance. Schiltz was forced to quit her job, too dizzy to even walk to the bathroom without grappling for the walls and sliding on the floor. Doctors told her the damage was permanent.

Schiltz agreed to test-drive the repurposed device. Every week, she came into the lab and placed the prototype strip in her mouth for several hundred seconds at a time. She would lean forward in the chair, feet and knees together, hands resting precariously on her lap. Even sitting like this was difficult for her. But for those short periods that the device was turned on, Schiltz found she was able to sit still without bobbling like a doll.

One day, the scientists asked her to try taking the strip out of her mouth after a twenty minute session. Bach-y-Rita stood behind her, his arms on either side of her body to catch her if she fell. The other scientists watched from the sidelines, anxious to see if their patient would collapse.

She didn't.

"It feels like it's still in my mouth," Schiltz

**"It was the most exciting time in my life. So heady. The anticipation of what was possible."
Mitchell Tyler**

said cautiously. She stood perfectly straight, eyes closed, in front of the table.

They decided to see how far they could push her. The scientists followed Schiltz outside and watched in amazement as she walked normally around the parking lot. As it slowly dawned on Schiltz that she wasn't going to tip over, she became bolder, jogging around the lot. She walked along the top of a wooden fence, balancing one foot in front of the other. She slow-danced with Bach-y-Rita alongside the building, laughing and crying at the same time.

That first time, the residual effects wore off after about an hour. But as Schiltz continued to train, the after-effects lasted longer and longer, until just one twenty minute session in the morning was enough to sustain her for the entire day.

"The longer the [device] was in my mouth, the longer the residual!" she wrote in her journal. "And the more I started to become Cheryl again."

Schiltz and Weihenmeyer became poster children for the Brainport, which Wicab confidently predicted would be released commercially within a year or two. F. Owen Black, a

researcher in Oregon who was helping test-drive the device with his own patients, told the *New York Times* that his patients were begging to continue using it.

"A little more funding and the system may soon fit into a wireless retainer that can snap onto the roof of the mouth," promised a *Wired* article written around that time. "Videogamers will have a sixth sense. Navy SEALs, who complain that night-vision goggles destroy their eyes' natural ability to adjust to the dark, will scan dark beaches with their taste buds. Pilots will vibrate their way home. And the blind will see."

Part of the public's interest in the Brainport owed to its essential strangeness. Articles alternatively described it as a "special lollipop," "a camera jacked into the tongue," and a "USB port to the brain." But the Brainport was more than a sci-fi curio or a therapeutic oddity. It was the final piece of the puzzle, the prize at the end of an arduous struggle. It was a validation of forty years of Bach-y-Rita's life. It was Bach-y-Rita's proof that the brain could dramatically change.

All the while, neuroplasticity continued to gain traction in the scientific community. Bach-y-Rita was wild with excitement each time he discovered a paper that corroborated his claims. He would rush into the laboratory, waving the latest publication in one hand, grinning madly from ear to ear.

The Fall

Everything, finally, was coming together. That may be why Bach-y-Rita didn't pay too much attention when he developed what

seemed like the early stages of pneumonia. He remained sick through Christmas vacation, then six weeks of guest lectures in France. When, one day in February 2004, he coughed bright red blood into his hand, he finally agreed to visit the hospital for a consultation.

It was there that Bach-y-Rita discovered that he was dying.

Though he had never smoked cigarettes and jogged every morning rain or shine, Bach-y-Rita had late-stage lung cancer. The doctors estimated that he had about six months left to live.

Bach-y-Rita's priority now was to leave his company on firm footing. He wanted to create forward momentum with the Brainport and to ensure that his family would be taken care of after he was gone. To do that, he knew that he needed to find Wicab someone with real business experience. The company had gone through two CEOs already, and the pressure to find someone who could handle their financial matters was mounting. They now they had eight full-time employees to manage—including Schiltz, who served as a secretary and occasional trainer for new Brainport users, and Yuri Danilov, a hulking neurophysiologist from Russia—as well as the part-time services of freelance programmers, writers, and lawyers. Tyler only drew a salary for half the time he worked, and Bach-y-Rita earned none at all.

One of Bach-y-Rita's neighbors, another UW professor, suggested Wicab try Robert Beckman. Beckman had served as the CFO for the neighbor's own medical start-up and had experience that seemed to match Wicab's needs. He was intrigued by the Brainport, but unimpressed with the company's apparent inability to get their technology into the hands of the pub-

lic. To Beckman, the company was far too consumed with theory, the scientists clearly scattered. Their ever-growing list of possible applications for the Brainport was not a sign of their ambition, but their lack of focus.

"Stop doing research and start selling products," he said.

Beckman pushed hard for Wicab to start official trials for government approval on the Brainport. The scientists balked at first, but eventually agreed to try, opting to focus first on the vestibular device.

As the trials ramped up, Bach-y-Rita scaled back his role in the company, though he continued to give talks, write papers, and brainstorm new research ideas with collaborators around the world. He also regularly fielded emails from patients who were hopeful that they could use his inventions to change their lives.

"Dr. Bach-y-Rita, I am one of the luckiest people in the whole world," wrote one subject whose vestibular system had, like Schiltz's, been ravaged by gentamicin. "I know you would not be too surprised of my success with the balance improvement because you know what Brainport can do, but I can tell anybody else that it has been a miracle for me."

Bach-y-Rita responded to each missive cheerfully, assuring well-wishers that his cancer was on the mend and hinting at the Brainport's imminent release. But this was a rosy version of reality. Chemotherapy drained more and more of his energy. He spent most of his time at home, where colleagues would visit often to give him updates on their work. He lost his thick head of Einstein hair, and stopped going for his morning runs. He asked conference organizers to arrange hotel rooms on the first floor, so he

wouldn't have to expend precious energy climbing stairs. Headaches made it hard to sleep.

His doctors put him on carboplatin and cisplatin, two cancer drugs with serious inner ear side effects. Bach-y-Rita began to have trouble balancing, though he resisted admitting that there was a problem. Soon, wherever he went, a friend or family member would be glued to his side, anxious to ensure the world-famous neuroscientist didn't fall down.

Several brutal falls and twelve stitches later, Bach-y-Rita decided to try using the Brainport himself. Tyler and Danilov rigged up a custom model for him. The helmet was simplified to be more user-friendly, and the software was stripped of any elaborate and potentially buggy features. Schiltz offered to train Bach-y-Rita on the device, as she had for so many subjects already in the trials.

Bach-y-Rita did not write much about the training, though he reported to friends and colleagues that he found the device helpful. Schiltz, on the other hand, was deeply moved by the experience. Helping Bach-y-Rita to steady himself in their first session, she was struck by the image of a doctor transformed into his own patient.

"Thank God he couldn't see me, because I was just sobbing," she said. "He changed my life, and here I am trying to help him."

A few months later, Bach-y-Rita died.

Splintered

Once Bach-y-Rita was gone, the relationship between Beckman and the remaining scientists rapidly deteriorated. The scientists found



Paul Bach-y-Rita at home, after undergoing chemotherapy.

Beckman myopic and narrow-minded; he saw them as impractical daydreamers. They thought he was pushing too hard to commercialize; he thought they weren't pushing hard enough. Arguments broke out more and more often.

Only in the experimental trials did anything appear to be going well. Wicab had recruited over sixty wobblers from around the country. Half received treatment with the real Brainport, while the other half used a fake one that vibrated in random patterns. To prove that the device really worked, Wicab needed to perform a double-blind study—that is, neither the scientists nor the subjects knew who was in which group. All subjects performed training exercises similar to the ones Schiltz had used during her early sessions at the university laboratory.

As the trials came to an end, Wicab un-

blinded the study. The results were crushing. About 62% of the subjects in the experimental group had improved—but so had almost exactly as many of those in the control group. In other words, the study showed no meaningful difference between the group who had used the real Brainport and the group who had used a fake. The study did not prove that the Brainport worked.

To Beckman, this was the end of the story. It was time to shut down work on the vestibular device.

The scientists, on the other hand, were incensed. This was one study, they argued. He had pushed them into testing the device before they were ready. They maintained that the study design wasn't strong enough to dismiss the technology entirely, and that they hadn't been sufficiently selective when choosing subjects for the

trials.

One by one, Beckman asked each of the scientists to leave Wicab. Danilov and Tyler returned to their laboratory at UW, where they continue to work with Kaczmarek on different tongue devices. They now believe that the mere experience of training with a tongue device can be beneficial—even if the stimulation patterns are random. In other words, they think that sensory substitution has nothing to do with it.

The scientists had tossed this idea around with Bach-y-Rita during the last year of his life.

“He was reluctant to embrace it,” Tyler said, though he thinks Bach-y-Rita was starting to come around to his side towards the end. “He could die a happy man knowing that his crazy ideas were in good hands and that we in the next generation were going to take it places that he hadn't even imagined.”

The scientists are still in the testing phases of their new ideas. The university has not granted a patent for their new device, which uses different stimulation patterns, and the leadership at Wicab maintains that the laboratory's work violates their patent on the Brainport.

Beckman continues to serve as Wicab's CEO to this day. He oversees a new set of employees, all of whom were hired after Bach-y-Rita's death, and they remain in the same set of offices just outside Madison, where the focus is now entirely on the vision device. Though Wicab still does not have FDA approval to sell products in the United States, Beckman predicts they might have it by the end of the year.

On the FAQ page of the company website, *Is this vision?* is listed as the top question.

“No, it is more like a 400 point refreshable

Braille display from which you learn to interpret the bubble-like patterns on their tongue as representative of objects in their surroundings,” the site says.

I asked Beckman about this stance when I visited Wicab a few days after my arrival in Wisconsin. Their position, I said, seems a pale imitation of Bach-y-Rita's own views of his device.

Beckman said that, from a marketing standpoint, describing the Brainport as vision is problematic.

“Our aim is not to mislead people,” he says. “If you thought that you were going to eliminate your cane or your seeing eye dog, you would be misled about what the kind of capabilities are of this device.”

Though Wicab no longer develops vestibular Brainports, they will still service an existing devices if it breaks. Beckman estimates that there are about a dozen users left in the world. One of these is Schiltz, who still uses the Brainport every morning.

After talking to Beckman, I asked to try a Brainport for myself. An employee—a young woman fresh off graduate school at UW—helped me to slip one on. It felt just the way that everyone had described it: cool and metallic, curiously ticklish, fizzing like one hundred tiny bubbles on my tongue. She rolled a white softball in front of me, and I felt the electrodes shimmer in a circular shape from right to left. I closed my eyes and tried to imagine seeing the world this way.

The House on the Hill

I look up from Bach-y-Rita's memoirs and

realize night has fallen.

Esther is over in the kitchen. She's cooking Catalan dishes, the food Pedro used to make in Bach-y-Rita's childhood home: some kind of savory fish with thick bread, pomegranate seeds steeped in red wine and sugar. She speaks to one of the cats in Spanish, her voice too quiet to make out. Through the window I can see the garden covered in a thick layer of ice and snow.

Everyone seems to agree on one count: that they are doing what Bach-y-Rita would have wanted. On my part, I have no more records to go on. The memoirs don't cover the last few years of Bach-y-Rita's life. Even his emails become shorter and sparser near the end. All I have is the people who are left, and these old papers, and my best guess.

I ask Esther for her opinion. Did Bach-y-Rita ever question his confidence in his theories?

"He had his moments of doubts," she answers, in her lilting Mexican accent. She sits beside me at the little table, leaning between two different piles of books. "He says, 'Well, I see it so clearly, and nobody else, maybe I'm wrong.' But then something would happen that would show, no, I have to follow this path."

It is comforting to think of science as a pure endeavor, as hurtling down a clearly lit path. Robert Hooke peers down his microscope and names the first cell. The Wright brothers lift off from Kitty Hawk in the first thrilling moments of flight. The story is uncomplicated and unemotional and clean.

And it is true that, when I read Bach-y-Rita's writing, I do not sense a sentimental man. But Bach-y-Rita's process was unmistakably messy. He dug in the trash for equipment,

fought with his superiors, and mismanaged his money. His students scattered themselves into disparate corners, disappointed and unwilling to reconcile. His invention remains, nearly half a century after its inception, out of the reach of the people who might need it most, and in danger of being made obsolete by different and more advanced technology. In the end, his tale did not come together.

But Bach-y-Rita disdained scientists who spent too much time focusing on the details of their disciplines, who got tripped up in their focus on a single, narrow slice. He felt their insistence on the specifics weighed science down.

"They have or expect to be able to have all the answers. Their evidence is objective and quantifiable and usually fits within the existing conceptual substance of their particular scientific discipline," he writes. "But [this approach] misses the essential power and meaning of the brain, its role in very complex issues; its ability to produce so much more than the sum of its parts; its role in our very humanness."

The history of science is filled with men and woman who got the particulars wrong but the grand view right. Bach-y-Rita's legacy is his dedication to his work, his bravery in fighting for a radical theory, his passion for finding a way to heal the broken. It is our choice now to decide what happens next.

"I prefer to consider my story unfinished," Bach-y-Rita writes, at the end of another opening draft.

SOURCE NOTES

The Bach-y-Rita family generously granted me access to Paul Bach-y-Rita's private papers. All unattributed quotes from Bach-y-Rita come from his unpublished memoirs or email records. Scenes have been recreated using a combination of his papers, quotes from personal interviews, and—when available—video footage.

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ACKNOWLEDGMENTS

This work would not have been possible without the help of many people. My most heartfelt thanks go out to Esther and Andrea Bach-y-Rita, who took me in for two weeks in January. You shared your home and your lives with me.

On that note, I would also like to thank all those who took the time to speak with me: Aimee Arnoldussen, George Bach-y-Rita, Robert Beckman, Yuri Danilov, Richard Hogle, Kurt Kaczmarek, Ronald Kalil, Peter König, Cheryl Schiltz, Kim Skinner, Lindsay Spencer, and Mitchell Tyler.

Thanks to the students of MIT GPSW's class of 2013. For the past year, you have been both my critics and my friends. Special shoutouts in particular to my superb volunteer second readers: Leslie Baehr, Alison Bruzek, and Zahra Hirji.

Also Ajay Major, who checked my science, and Corey Rutkin, who found a typo.

The first advice I received from my thesis advisor, Seth Mnookin, was to walk around and pretend that I was writing a biography. It worked. Thank you for the excellent, if illegible, guidance.

Finally, as always, I must thank Dr. Maura Kates Rutkin and Alan S. Rutkin '80. This is all your fault.

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