The Next Brainiacs

This is the story of the most fearless entrepreneur ever: the human brain.
By John Hockenberry

When you think disability, think zeitgeist. I'm serious. We live at a time when the disabled are on the leading edge of a broader societal trend toward the use of assistive technology. With the advent of miniature wireless tech, electronic gadgets have stepped up their invasion of the body, and our concept of what it means and even looks like to be human is wide open to debate. Humanity's specs are back on the drawing board, thanks to some unlikely designers, and the disabled have a serious advantage in this conversation. They've been using technology in collaborative, intimate ways for years - to move, to communicate, to interact with the world.

When you think disability, free yourself from the sob-story crap, all the oversize shrieking about people praying for miracles and walking again, or triumphing against the odds. Instead, think puppets. At a basic level, physical disability is really just a form of puppetry. If you've ever marveled at how someone can bring a smudged sock puppet to life or talked back to Elmo and Grover, then intellectually you're nearly there. Puppetry is the original brain-machine interface. It entertains because it shows you how this interface can be ported to different platforms.

If puppetry is the clever mapping of human characteristics onto a nonhuman object, then disability is the same mapping onto a still-human object. Making the body work regardless of physical deficit is not a challenge I would wish on anyone, but getting good at being disabled is like discovering an alternative platform. It's closer to puppetry than anything else I can think of. I should know: I've been at it for 25 years. I have lots of moving parts. Two of them are not my legs. When you think John Hockenberry, think wheelchair. Think alternative platform. Think puppet.

Within each class of disability, there are different forms of puppetry, different people and technologies interacting to solve various movement or communication problems. The goal, always, is to project a whole human being, to see the puppet as a character rather than a sock or a collection of marionette strings.

When you meet Johnny Ray, it's a challenge to see the former drywall contractor and amateur musician trapped inside his body, but he's there. Ray, a 63-year-old from Carrollton, Georgia, suffered a brain-stem stroke in 1997, which produced what doctors call "locked-in syndrome": He has virtually no moving parts. Cognitively he's intact, but he can't make a motion to deliver that message or any other to the world.

Getting a puppet with no moving parts to work sounds like a task worthy of the Buddha, but a pioneering group of neuroscientists affiliated with Emory University in Atlanta has taken a credible stab at it. In a series of animal and human experiments dating back to 1990, Philip Kennedy, Roy Bakay, and a team of researchers have created a basic but completely functional alternative interface using electrodes surgically implanted in the brain. In 1996, their success with primates convinced the FDA to allow two human tests. The first subject, whose name was withheld to protect her privacy, was a woman in the terminal stages of ALS (Lou Gehrig's disease); she died two months after the procedure. The second was Johnny Ray.

Kennedy, who invented the subcranial cortical implant used in these operations, wanted to create a device that could acquire a signal from inside the brain - a signal robust enough to travel through wires and manipulate objects in the physical world. Making this happen involved creating new access points for the brain, in addition to the natural ones (defunct in Ray's case) that produce muscle motion. Bakay has since moved to Rush-Presbyterian-St. Luke's Medical Center in Chicago, where he's part of an institute devoted entirely to alternative brain-body interfaces. The soft-spoken doctor wouldn't describe anything he does as show business, but to me the results of his work sound like a real-world version of the nifty plug Neo/Keanu sported in *The Matrix.*

"We simply make a hole in the skull right above the ear, near the back end of the motor cortex, secure our electrodes and other hardware to the bone so they don't migrate, and wait for a signal," Bakay says. The implant is an intriguing hybrid of electronics and biology - it physically melds with brain tissue.

"We use a small piece of glass shaped like two narrow cones into which a gold electrical contact has been glued," Bakay says. "The space in the cones is filled with a special tissue culture, and the whole thing is placed inside the motor cortex." The tissue culture is designed to "attract" brain cells to grow toward the contact. When brain cells meet gold, the electrical activity of individual cells is detectable across the electrode. Gold wires carry signals back out of the skull, where they are amplified. This produces a far more sensitive and usable signal than you get from surface technology like the taped-on electrodes used in EEGs.

To get a broad sense of what the patient's brain is doing, neurologists perform magnetic resonance imaging and compare changes in the motor cortex with voltages monitored through the electrodes. Then the doctors get really clever. The patient is encouraged to think simple thoughts that correspond to distinct conditions and movements, like hot/cold or up/down. Gradually, the doctors extract and codify electrical patterns that change as a patient's thoughts change. If a patient can reproduce and trigger the signal using the same thought patterns, that signal can be identified and used to control, say, a cursor on a computer screen. The technique is very crude, but what Bakay and his colleagues have demonstrated is a truly alternative brain-body interface platform.

Ray's implant was installed in 1998, and he survived to start working with the signals, which were amplified and converted to USB input for a Dell Pentium box. In the tests that followed, Ray was asked to think about specific physical motions - moving his arms, for example. Kennedy and Bakay took the corresponding signal and programmed it to move the cursor. By reproducing the same brain pattern, Ray eventually was able to move the cursor at will to choose screen icons, spell, even generate musical tones. That this was in fact an alternative platform, a true brain-machine interface, was demonstrated after months of tests, when Ray reported that the thoughts he used to trigger the electrode - imagined arm motions - were changing. He was now activating the electrode by thinking about facial movements, and as he manipulated the cursor, doctors could see his cheeks move and his eyes flutter. Kennedy and Bakay had predicted that Ray's focused mental activity might result in neurological changes, but to see actual facial movements was a surprise. It didn't mean that his paralysis was receding, rather that his brain had tapped into capabilities rendered dormant by the stroke. The results showed that Ray's thoughts about motion were triggering clusters of motor neurons. How? Kennedy and Bakay presumed the implant had put various motion centers in Ray's brain back into play. Disconnected from the body/hardware they once controlled,

these neurons now had a crude way to interact. Adapting to the new platform, Ray's brain was demonstrating a flexibility standard worthy of Java or Linux.
As the brain cells in and around Ray's implant did what he asked them to do, the imagined sensation of moving his body parts gradually disappeared altogether. One day when his skill at moving the cursor seemed particularly adept, the doctors asked Ray what he was feeling. Slowly, he typed "nothing."

Ray was interacting directly with the cursor in a way similar to how he might once have interacted with his hand. "People don't think, 'move hand' to move their hands unless they are small children just learning," Bakay explains. "Eventually the brain just eliminates these intermediate steps until the hand feels like a part of the brain." The description reminds me of how I've heard Isaac Stern describe his violin as an extension of his body. I think of my wheelchair the same way.

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The fact that Ray's cursor is indistinguishable from almost any other prosthesis raises an important philosophical question: Because of the implant, is a Dell Pentium cursor now more a part of Johnny Ray than one of his own paralyzed arms?

The National Institutes of Health is interested enough in this technology to have provided $1.1 million in seed funding for an additional eight human tests that will continue over the coming year. Bakay hopes the next patients won't be as profoundly disabled as the first two. "The more kinds of applications we find for this," Bakay says, "the more we learn about it."

From my perspective as a wheelchair puppet, life is a question of optimizing the brain-machine interface. In the beginning, this was far from obvious to me. My spinal cord was injured in a car accident when I was 19 - an utterly random occurrence in which a woman picked me up while I was hitchhiking and later fell asleep at the wheel. She died. But I emerged from her crumpled car, then from a hospital, and resumed my life. I looked for a way to describe what I was doing: Rehabilitation was a word for it. Courage was a word for it. Coping was a word for it. But none of those labels even approached the reality of what relearning physical life was all about.

Since then I've been improvising motion by merging available body functionality (arms, hands, torso, neck, head) with a small arsenal of customized machines (wheelchairs, grabbers, cordless phones, remote controls, broomsticks with a bent nail pounded into the end). At times I've seen my own quest for new physical ability in odd places - a musician seeking virtuosity, an athlete seeking perfection. I've become convinced that the process of fine-tuning one's mobility through practice and the use of tools is as old as humanity itself. I've come to believe it is identical to an infant's task of developing coordination while facing near-zero available functionality of legs, arms, and muscles. There is no better puppet show than watching your own children teach themselves to walk. In my case, it involved watching Zoë and Olivia, my twin daughters. Their strategies were complicated improvisations that proceeded from observing the world around them. Olivia made especially good use of her hands and arms, grabbing tables, drawer handles, and the spokes on my wheelchair to pull herself upright, where she would stand in place for long periods of time, feeling the potential in her chubby little legs.

Zoë spent weeks on her stomach flapping like a seal, hoping somehow to launch spontaneously onto her feet. She did not see her legs as helpful, and to her credit, in our house walking was merely one of two major models for locomotion. One morning, well before she was 2 years old and long before she walked, I placed Zoë in my wheelchair and watched as she immediately grabbed the wheels and began to push herself forward as though she'd been doing it for years. She had even figured out how to use the different rotation rates of the rear wheels to steer herself. Zoë had grasped that the wheelchair was the most accessible motion platform for someone - in this case, an infant - who couldn't use her legs. She smiled as she looked at me, with an expression that said something like, "Give up the wheels, Mr. Chairhog."

Zoë and Olivia walk perfectly now, but their choices in those formative weeks were startlingly different. In both, the same brain-machine transaction was at work creating functionality from what was available. Engineers and designers have discovered that this is a process as distinctive as fingerprints. Every person solves problems in his or her own way, with a mix of technology and body improvisation. The variables are cultural and psychological, and precise outcomes are difficult to predict - but they determine what technology will work for which person. Think puppetry as a universal metaphor for the design of machines.

Jim Jatich has been a cyborg puppet for years now and is proud of it. A 53-year-old former engineering technician and draftsman from Akron, Ohio, Jatich is a quadriplegic who first donated his body to science back in 1978. A near-fatal diving accident the year before left him without use of his legs and hands, and with limited use of muscles in his arms and shoulders.

The computer term *expansion port* was unknown back in the late '70s, but Jatich's doctors at Case Western Reserve University in Cleveland arrived at the same idea. They imagined building an alternative path around Jatich's injured spinal cord to restore a local area network that could be controlled by his brain.

In a series of operations and therapies starting in 1986, Jatich became the first human to receive surgically implanted electrodes in his hands to mimic nerves by stimulating the muscles with tiny bursts of electricity. The process is known as functional electrical stimulation, or FES. By using a shoulder-mounted joystick to trigger patterns of electrical impulses, Jatich was able to open and close his hands. Others have since used the technology to move leg muscles and allow the exercise of paralyzed limbs.

Two years ago, a research assistant named Rich Lauer came to Jatich with the suggestion that he think about tapping into his brain directly. "This one sounded real crazy," Jatich says. "He claimed he had a way to see if I could control first a computer cursor and then maybe the muscles of my hand, just by thinking. I thought it was BS," he says with a wink. "You know, brain science."

Researchers placed a skullcap containing 64 electrodes on Jatich's head. These produced a waveform of his brain activity, though the signal was much weaker than the one obtained from Johnny Ray's cortical implants. Like Ray's doctors, the researchers asked Jatich to concentrate on simple but opposite concepts like up and down. They carefully observed the EEG for readable changes in brain patterns. They used software to measure the maximums and minimums in his overall brain wave and to calculate the moving averages in exactly the same way stock analysts try to pull signals from the

jagged data noise of the stock market. A pattern was identified and fashioned as a switch: Above the average equaled on; below the average, off. With this switch they could control a cursor's direction and, as a hacker might say, they were "in."
When I used the Ibot for the first time, the chip was making the wheels move, but my brain's own sense of balance merged instantly with the machine. Its decisions seemed to be mine.

While Jatich's doctors worked to optimize the software, he concentrated on a wall-size computer screen. Monitoring changes in his EEG and modifying the programming accordingly produced a kind of biofeedback. Gradually, like Johnny Ray, Jatich was able to move a flashing cursor to the middle of a projected line. The goal was to have the computer search for distinct, recallable brain-wave patterns that could be used to control any number of devices that could be connected to a chip.

Jatich says there was nothing portable about the equipment - he found the electrode skullcap cumbersome and the whole system a bit rickety. "Cell phones down the hall at the hospital would cause the thing to go blank every once in a while." But the enterprise did deliver a breakthrough he hadn't anticipated.

"When I got downstairs after the first couple of experiments," he says, "I was sitting outside, waiting for my ride, and it hit me. I had caused something to move just by using my mind alone. The tears streamed down my face, because it was the first time I had done that since I got injured." Jatich says he felt like "a kid being handed keys to a car for the first time."

Going from manually controlled FES to brain implants that bypass the spinal cord to produce muscle movement would represent a significant leap. But Ron Triolo, a professor of orthopedics and biomedical engineering at Case Western and a clinician at the Cleveland FES Center, thinks this is possible. He sees this leap as the possible fulfillment of FES's many, often outsize, promises for people with disabilities. The challenge is immense, but, as Triolo puts it, "Failure is closer to success than doing nothing. I've seen some of the preliminary work on cortical control and it's impressive. Clearly, it's going to pay off eventually."

Since Jatich's first implantable hand device was installed, the technology for nerve stimulation has advanced to the point where the reliable, long-lasting electrodes in both of his hands are barely visible, require practically zero maintenance, and have become more or less permanent parts of his body. For the last 15 years, he's used a shoulder joystick controller to move his right hand. Controlling his left hand is an IJAT, or implantable joint angle transducer, which employs a magnet and sensor attached to the bones of the wrist. Slight movements trigger complex hand-grasping motions. The computer mounted on the back of Jatich's wheelchair stores the software that helps produce as many as five different motions, which he can specify depending on whether he wants to hold a pencil and write or grasp a utensil and feed himself - capabilities he would not otherwise have at all.

Over the years, Jatich has gone from being a person completely dependent on others to having some degree of autonomy. His grasping ability means he can use a computer and feed himself, among other simple tasks. In the past few years, Jatich has been able to do some mechanical drawing, using his hand devices along with commercially available computer-aided design systems.

Thinking about taking the next step - an implant that might allow him to connect his brain, via computer, to his electrode-filled hands - excites him. "You could sure get a hell of a signal from the surface of the brain as compared to the electrodes in that ugly skullcap," Jatich says. He speaks as though he's talking about a science fair project and not the tissue under his own cranium. "I would have to think hard about it, but if they could deliver on their promises, it would be great. I would do it in a minute."

Suddenly, million-dollar grants are being thrown around to investigate the possibilities of direct interaction with the brain. While much of the study is geared toward finding ways to reopen avenues closed by massive paralysis, it also raises the possibility of creating alternative brain outlets to the world in addition to the ones we were born with. The FDA won't allow it yet, but there's no scientific barrier preventing some brave pioneer from adding a new ability - for instance, a brain-controlled wireless device to regulate climate and lighting in one's home. In November, British cybernetics professor Kevin Warwick plans to have a chip implanted next to his arm's central nerve bundle so he can experiment with sending and receiving digital signals (see "Cyborg 1.0," *Wired* 8.02, page 144).

Deep brain stimulation is the overarching term for the therapies in development, and specific projects are under way to address severe nervous system disorders like Parkinson's disease, TBI (traumatic brain injury), and other locked-in syndromes. The NIH has embarked on an aggressive program to develop cortical control devices as the first truly practical neuro-prostheses. This is a kind of low-bandwidth alternative to the field of spinal cord research focused on repairing injured spinal tissue and restoring the original brain-muscle connection.

Dubbed "the Cure" by its passionate supporters, savvy marketers, and fundraisers, this vision of spinal cord repair has a much higher profile and is far better financed than FES and other alternative-interface explorations. The Cure has Christopher Reeve as its cash-gushing poster boy. FES has Jim Jatich. Cortical implant technology has Johnny Ray. Certainly, anyone who wakes up with a spinal cord injury is inclined to hope for a cure above all other options. But one would expect medical research strategies to be more detached from the emotional trauma of disability. As someone who has lived in a wheelchair comfortably for a quarter century, it is hard to justify why the Cure would be so favored over its alternatives.

Rush-Presbyterian's Roy Bakay expresses some frustration that his efforts directly compete with the Cure movement for funding. "We can do things for people now, whereas spinal cord research isn't going to pay off for a very long time, if at all. I'm not saying that spinal cord research shouldn't be conducted, just that [deep-brain stimulation] may be a more immediate solution for getting the brain to interact with the outside world." Others report that Reeve's visibility has made it more difficult to find people willing to try new technology involving surgery or implants. "They say they want to keep their bodies in good shape for when the Cure happens," says Jatich, who often counsels people considering FES.

Reeve was injured in a 1995 horse-riding accident; he can't move anything below his neck and needs assistance to breathe. Despite declaring shortly after the accident that he would someday walk again, Reeve is not pro-Cure to the exclusion of all other options. He has carefully maintained that he supports any endeavor that might help people with disabilities. He has muted his personal predictions about walking again, though he is still dedicated to the Cure. The movement Reeve helped create represents those who believe the body is the brain's best interface to the outside world. Certainly, there's nothing on the market to give the fully functioning body any serious competition. Yet for people without one, supplementing bodies with onboard technology to increase functionality is a way around the wait for a full cure.

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It's a familiar trade-off: As every technology develops, there is the tension of using the interesting but cumbersome first-wave device versus waiting until the tech is small enough, convenient enough, or integrated enough with the body to bother with it. This trade-off has been debated within the disabled community for generations, and it is just starting to be reflected in the broader culture.

The field with perhaps the best track record in dealing with complicated brain-machine interfaces is communications technology for the sensory- and voice-impaired. It's also the area in which the trade-offs between functionality and ease of use are most critical. With computers, turning text into voice is considerably easier than making a device that operates with the ease and speed of speech.

"There is a real issue of gadget tolerance, and people have finite limits," says Frank DeRuyter, chief of speech pathology at Duke University Medical Center and a leader in the field of augmented communication. "Our smart systems need to be environmentally sensitive or they don't get used." DeRuyter has worked with all kinds of communications devices, from primitive boards - little more than alphabets and pictures used by noncommunicators to slowly construct sentences by pointing - to more sophisticated electronic speech-synthesis devices. All have their own advantages and disadvantages, which are ignored at a designer's peril.

DeRuyter describes how designers can be locked into narrow functionality traps that keep them from seeing the world the way the disabled do. "Talking is a portable communications system that enhances every other activity. We used to put some of our noncommunicators into the pool each day, and we could never figure out why they hated it. Then we realized that by removing electronic communications boards that couldn't tolerate water, their pool time was the equivalent of being gagged. We designed some simple, waterproof alphabet boards and the problem went away. Pool time became fun." Michael B. Williams is an augmented communications technology user and a disability rights activist from Berkeley, California. He relies on three devices to communicate: two VOCAs (voice output communication aids, basically chip-controlled text-to-voice synthesizers) and a low-tech waterproof alphabet board. The board, he told me in an email, is there "for when California's power goes out," and for "private thoughts in the shower." Williams' smaller VOCA is a spell-and-speak device that is handy enough for dinner table conversations. His largest and most advanced VOCA is "heavy and hard on the knees," but has rapid word access that enables Williams to give public speeches in a kind of partial-playback mode, which he has been doing for years now.

Diagnosed with cerebral palsy as a young child, Williams struggled with the speech therapy recommended by medical and educational professionals to enable him to control his mouth and use his own voice. His eventual rejection of this mode of communication was a simple technology decision; the brain-machine interface called speech is, in his case, seriously flawed. He describes his voice as being "like used oatmeal," and he has instead acquired the tech to live on his own terms, according to his personal specifications. When Williams gives speeches, his advanced VOCA offers the choice of 10 different programmed voices (he prefers the one called Huge Harry for himself). When he quotes someone, he uses a different voice, and it sounds like two people are on stage.

"This bit of electronic tomfoolery seems to wow audiences," he says in an email, his sly showman's confidence coming through. So when you think about Williams, don't think courageous crippled guy giving a speech. Think puppetry, ventriloquism, Stephen Hawking.

Williams says it's impossible to evaluate any technology on function alone. For instance, he says the value of his ability to communicate is directly related to his mobility. "Someone recently asked me, 'If you were given a choice of having a voice or a power wheelchair, which would you choose?' This is a no-brainer for me. I would choose the power wheelchair. What would I do with only a voice - sit at home and talk to the TV? Another thing I wouldn't give up is my computer. With a computer and a modem I can get my thoughts, such as they are, out to the world."

Frank DeRuyter says designers need to think in the broadest possible terms when they approach human-interface technology. "We're just beginning to realize the importance of integrating movement technology with communications tech. We see that a GPS device can powerfully increase the functionality of a communications board. When people roll their wheelchairs into a grocery store, the GPS will automatically change the board's stored phrases and icons into ones relevant to shopping. Shifting context as you move - that's what the brain does. Now we can do it, too."

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This idea of optimizing a personal brain-machine interface is as much an issue for engineers at Nokia, Motorola, and other manufacturers of wireless technology as it is for people designing for the disabled. Companies need people to actually buy and use their devices, not just gawk at them in glossy trade magazines. On a street in Manhattan last fall, it hit me: four people, one intersection. One man with a cell phone and headset was talking calmly and loudly, oblivious to the rest of the world. Another had a cell phone handset pressed to his head and was attempting to get a scrap of paper, one-handed, from his briefcase. A woman was at the pay phone looking for a quarter. The fourth person stood waiting for the light to change, looking at his wristwatch. If the four were frozen at that intersection, how would future paleontologists construe their fossilized differences? Four people, four different capabilities, four distinct species. Five, if you count me. Man with wheelchair ... no cell phone.

"There is a calculus in this field that we have come to know from decades of experience," says Ron Triolo of the Cleveland FES Center. "People don't want to lose anything they already have, and that includes wasted time, as well as an arm or a leg. But if they can increase functionality without losing anything, they want to do that.
"How we thought people would benefit from FES is different from what actual users have told us," he continues. "For instance, we imagined that FES would be of no value unless

it was nearly invisible and provided a level of function comparable to the pre-injured state. We discovered we were talking from an ivory tower. People enjoy the ability to make even the most rudimentary physical motions and don't particularly care if those motions don't lead to jobs or activities associated with their life pre-injury."

Triolo describes novel ways in which disabled people have taken off-the-shelf equipment and used it in sometimes alarming ways, well beyond the designer's imagination. A man who uses his FES system to stand has improvised a way to clumsily hop up and down stairs. A female FES user recently sent Triolo a picture of herself standing, à la *Titanic,* on the bow of a boat under full sail. "If she had gone into the water ..." He pauses to find words to convey both his fear (of massive product liability, perhaps) and his admiration for the woman's guts. In the end he can only say, "Well, you know."

In my case, projecting my independence as a collaboration between machine, body, and brain is an important message, if difficult to convey. I can coast flat out and slalom effortlessly around pedestrians, and produce equal measures of awe and terror. No matter how skilled I am in my chair, people often wonder why I don't use a motorized one. I love using a machine I never have to read a manual to operate. Why can't they see the value of my ragged optimizing strategies? Think Xtreme sports, hot-dogging. There are also deep cultural factors that sometimes surprise and frustrate designers of technology for the disabled. One of the first machine-to-brain devices, the cochlear implant, was heralded as a miracle cure for some forms of deafness when it was fully introduced in the 1990s. The electronic device, mounted inside the ear, works like FES on muscle tissue. In this case, the electrodes, responding to sound, stimulate different regions of the cochlea at a rate equivalent to a 91K modem. The cochlea, in turn, sends signals to the brain that can be processed as sound. The device requires training the brain to decipher the implant's stimulus and does not replace or completely restore hearing. Many deaf people view the implant as a form of ethnic cleansing and physical mutilation. The cochlear implant, according to opponents, is a direct confrontation to the shared experience of deafness, the language of signing, and all of the hot-dogging improvisations deaf people have developed over many generations to function without hearing.

Brenda Battat is the deputy executive director of Self-Help for Hard of Hearing People, a national organization in Bethesda, Maryland, that counsels people who are considering traditional hearings aids and cochlear implants. She believes opposition to the cochlear implant is moderating. Still, she says, technology requires an investment of time and emotion that engineers and users often aren't aware of. "Whatever technology you use, you're still a person with a hearing loss. When the battery breaks down, there is a moment of absolute panic. It's a very scary feeling." That feeling of dependence relates as much to the type A technoid having seizures over the dead batteries in his BlackBerry as it does to Johnny Ray adjusting to the imperfections of his brain implant. Anyone using an assistive technology system expects it will work every time, under a wide variety of conditions, without degrading any of their existing capabilities.

Perhaps the best example of a technology solution that interacts directly with the brain is the Ibot wheelchair, now in the final stage of prelaunch testing by Johnson & Johnson and the FDA. Designer Dean Kamen wanted to create a transportation device that would have the equivalent functionality of walking, climbing stairs, standing upright, and all-terrain motion. To operate in upright, two-wheel stand-up mode, the Ibot uses an onboard computer and a system of miniaturized aviation-grade gyros to assess the center of gravity and deliver a signal to high-speed motors. These turn the wheels accordingly to compensate and keep the user from falling over.

My first impression of the machine was not positive. The Ibot is a cumbersome, complicated thing that makes you dread being stuck somewhere without a tool kit. But watch the Ibot balancing, making little rocking motions to keep it upright, and you feel as though you're in the presence of some humanoid intelligence.

When Kamen began testing his chair with disabled users, he discovered an eerie and unanticipated brain-machine interface. "Each person we took up the stairs said, 'Great.' They said great when we took them through the sand and the gravel and up the curb and down the curb. But when we stood them up and made them eye level with another person, and they could feel what it was like to balance, every single one of them started crying."

Kamen believes that people who use the Ibot in its two-wheel balancing mode are literally feeling the experience of walking, even though the machine is doing the work. "If you could get an MRI picture of the balance center of the brain of some person in a wheelchair who goes up on the Ibot's two wheels, I bet you'd see some lights go on," he says. "I'm convinced the brain remembers balancing, and that's why people feel so much emotion."

The brain-body-machine interface doesn't seem to need the body as much as we believe it does. We hybrids are part of a universal redrafting of the human design specification. I felt exactly that when I used the Ibot for the first time and stood upright. The chip was making the wheels move, but my brain's own sense of balance seemed to instantly merge with the machine. Its decisions seemed to be mine. No implants. No wires. It was truly extraordinary. Think FDR on a skateboard.

This raises a fairly revolutionary point about brains and the physical world. Bodies are perhaps a somewhat arbitrary evolutionary solution to issues of mobility and communication. By this argument, the brain has no particular preference for any physical configuration as long as functionality can be preserved.

Michael Williams believes that the disabled have helped humanity figure this out in terms of technology. He thinks people are rapidly losing their fear of gadgets. "The greatest thing people with disabilities have done for the general population is to make it safe to look weird. It's certainly true that the general population has glommed onto some principles of assistive tech. Just roll down the street and observe the folks with wires dangling from their ears. Look at the TV commercials featuring guys with computerized eyewear."

The history of assistive technology for the disabled shows that people will sacrifice traditional body image if they can have equivalent capabilities. It's a profound lesson for designers and people who irrationally fear brain implants. It perhaps has even more practical implications for people who are waiting for a cure to restore their functions. The brain-body-machine interface doesn't seem to need the body as much as we believe it does.

Think many different puppets ... same show.

For those open to the possibility, the definition of human includes a whole range of biological-machine hybrids, of which I am only one. The ultimate promise of brain-machine technology is to add functionality - enhanced vision, hearing, strength - to people without disabilities. There is nothing of a technological nature to suggest that this can't happen, and in small but significant ways it has already begun. The organic merging of machine and body is a theme of human adaptation that predates the digital age.

As I think about the quarter century I've spent in a wheelchair, there are almost no traditional concepts to describe the experience. As I weave around the obstructions of the world's low-bandwidth architecture, with its narrow doors and badly placed steps, I find my journey to be less and less some sentimental, stoic "go on with your life, brave boy" kind of thing and more part of a universal redrafting of the human design specification. I am drawn back to Michael Williams and his disarming motto: "The disabled have made it OK to look weird." There is such wisdom and promise in that statement.

People with disabilities - who for much of human history died or were left to die - are now, due to medical technology, living full lives. As they do, the definition of humanness has begun to widen. I remember encountering, on a street corner in Kinshasa in the former Zaire, a young man with the very same spinal cord injury as my own, rolling around in a fabulous, canopied hand-pedaled bike/wheelchair/street RV. He came up to me with a gleam of admiration for my chair and invited me to appreciate his solution to the brain-body interface problem. We shared no common language, but he immediately recognized how seamlessly my body and chair merged. That machine-body integrity is largely invisible to the people who notice only the medical/tragedy aspect of my experience. I could see how he had melded even more completely with his chair - in fact, it was almost impossible to see where his body left off and his welded-tube contraption began. It was clear he was grateful for my admiration.

As time has passed, I am conscious of how little I miss specific functions of my pre-accident body, how little I even remember them in any concrete way. I used to think this was some psychological salve to keep me from being depressed over what has been a so-far irreversible injury. I have come to believe that what is really going on is a much more interesting phenomenon. My brain has remapped my physical functions onto the physical world by using my remaining nonparalyzed body, a variety of new muscle skills, tools, reconfigured strategies for movement and other functions, and by making the most of unforeseen advantages (good parking spaces, for instance). This is something that has taken me years to learn.

My daughters have never known any other way of looking at me. As they grow older, they will no doubt be introduced by people around them to the more conventional way of thinking about their poor, injured, incapacitated daddy. I suspect they will see the flaws in this old way of thinking far more quickly than their little friends who come though our house warily regarding the man in the purple chair with wheels.

In a straightforward way that needs no psychological jargon to explain, my former body simply doesn't exist anymore. Like Isaac Stern and his violin, I am now part chair, with some capabilities that exceed my original specifications.

There's a very old story about a puppet that worked so hard to live in the real world, it eventually stopped being a puppet. The experience of interacting in the world connected this wooden puppet to the humans around him to the point where he was indistinguishable from them. An unstated corollary of the fable is that the humans were equally indistinguishable from the wooden puppet. I'm not lying.

Think Pinocchio. Think real boy.

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