Gary Linfoot, a U.S. Army veteran who was paralyzed in Iraq, used a bionic "exoskeleton" to walk around the Statue of Liberty on Veterans Day 2013.

GREAT STRIDES

Adaptive medical technologies enable stunning achievements by people with disabilities

By Buddy Levy

The climber moves smoothly up the vertical rock face, spidering up the sheer, 200-foot cliff of The Gunks (a nickname for New York state's Shawangunk Mountains). The man ascends with precision and grace, defying gravity, conventional wisdom and others' expectations of him as he clings to handholds and footholds each no wider than a coin.

The climber is Hugh Herr, and he's a double amputee who continues to climb mountains—now better than ever in his life—wearing two prosthetic legs he designed himself at the Biomechatronics research group of the MIT Media Lab in Cambridge, Massachusetts.

Hugh Herr's story is remarkable and transformative, a profound example of a new wave of modern innovation that combines science, human spirit and ingenuity to create groundbreaking adaptive technologies that allow people to do things once believed impossible. Along the way, these innovations, and the people making and using them, are changing the way we think about the term *disability*.

Herr always seemed destined for great heights. By age 8 he had climbed Canada's 11,624-foot Mount Temple, in Banff National Park, and by his teens he was considered one of America's climbing phenoms. Then, during a winter climb of New Hampshire's Mount Washington in January 1982, Herr and a climbing partner became lost in a whiteout and wandered for four days in subzero temperatures. When Herr was finally rescued, he was suffering from hypothermia and severe frostbite. After months of procedures attempting to save his damaged limbs, Herr's legs had to be amputated below the knees. He was 17 years old.

Herr had believed with certainty that he would die on the mountain. When he survived, he became inspired by the memory of Albert Dow, a rescue volunteer who was struck by an avalanche and died during the search for Herr and his partner. Herr vowed not only to walk again, but to climb, and maybe climb better than he had before. The prosthetics available at the time were crude passive limbs unsuited to the mountainous outdoor adventures that Herr had in mind, so he devoted his life to designing artificial limbs that would eventually emulate, and arguably even surpass, biological limbs. His innovations would improve the lives of amputees. Called "bionics," these motorized robotic prosthetics use computers and sensors to mimic biological limb function. Herr—who received a master's degree in mechanical engineering from MIT and a doctorate in biophysics from Harvard University—now directs research at the MIT Media Lab, where, as he puts it, "We build robots that attach to the body to enhance physicality."

Herr's long-term goal is nothing short of ending disability as we know it. He has designed and uses numerous types of prostheses: Some can be worn ice climbing; some are made for running; and others have fins for swimming and turn Herr into a real-life Aquaman.

Most impressive, perhaps, are the bionic joints he's designed, such as the BiOM Ankle System. Each BiOM ankle has three computers and 12 sensors in a control system that models missing reflexes and muscle motions. When correctly programmed, a BiOM ankle moves the same way a biological joint moves. Made with a combination of aluminum, titanium, silicone and carbon fiber, the ankle senses things such as exerted force on the ground and force on the musclelike system.

SIMON BRUTY / SPORTS ILLUSTRATED / GETTY IMAGES

Hugh Herr, who heads the Biomechatronics group at MIT Media Lab, had his lower legs amputated after suffering frostbite on a 1982 mountain climb. Today he designs bionic prostheses and uses them for climbing and other activities.

OPPOSITE: CRAIG BARRITT / GETTY IMAGES FOR INFINITE HERO FOUNDATION

KELLY JOHNSON

Multisport adventurer Erik Weihenmayer, who is blind, uses a Neptune BlueWave Intercom/ Mixer Unit to communicate with kayaking guides via Bluetooth wireless. With his support team, he aims to use the technology to kayak 277 miles of the Colorado River in 2014.

RIGHT (3): COURTESY: DS-NEPTUNE DEVELOPMENTS LTD.

The **Neptune BlueWave Intercom/ Mixer Unit** receives and relays transmissions among members of the kayak team, and to the system's recording unit.

A **Neptune Adapta-Com earpiece/ microphone** set fitted to a helmet allows each kayak team member to communicate.

A **Neptune BlueWave personal unit** (above) is clipped to the clothes of each kayak team member. Each unit is linked by a short cable to the earpiece and microphone fitted to the user's helmet and transmits to the intercom/ mixer unit.

The prosthetic ankles allow the wearer to walk with a natural gait and to ascend or descend stairs or hilly hiking trails.

Using advanced science and technology design, Herr is a leader in creating devices that may one day allow amputees to run faster than people with completely biological legs. Other pioneers are working to create a world in which full-body exoskeletons allow paralyzed people to walk, and a world in which blind people can use adaptive technologies to "see" in new ways.

Exoskeletons

In March 2009 in Brainerd, Minnesota, professional snowmobiler Paul Thacker, an Evel Knievel on snow, charged his 430-pound Polaris snowmobile toward a ramp at 90 miles per hour and flew 301 feet through the air, setting a new world record as the first person to jump a snowmobile over the length of a football field.

In November 2010, the Anchorage, Alaska, native was back home training for the Winter X Games when he crashed his sled on what was for him a routine jump. He hit the handlebars, fell awkwardly, and, as he lay on the ground following the landing, told his friends, "I can't feel my legs." Thacker had severely bruised his spinal cord at the T5 level. He was paraplegic—completely paralyzed in his lower body and legs.

During his rehabilitation at Craig Hospital in Denver, Thacker learned about a new rehabilitation tool—an exoskeleton—that would allow him to walk again in an assisted fashion. "They told me they had this new contraption created by a company called Ekso Bionics, and I agreed to be a crash-test dummy," Thacker says, with a laugh.

Exoskeletons are wearable, computerized robotic or bionic suits. They look a bit like the suit worn by the comic-book character Iron Man, and they allow people such as Thacker—and many others with severe neurological damage—to stand up and walk, sometimes for the first time in their lives.

CHICAGO IDEAS WEEK (CIW)

TODD WILLIAMS

Left: Paul Thacker, who is paralyzed in his lower body and legs, uses a mechanized exoskeleton for rehabilitation and assisted walking. **Above and right:** Thacker, strapped into a specialized seat, continues to compete as a snowmobiler.

The benefits are physiological and psychological. Exoskeletons function by integrating mechanical engineering, electrical engineering and computer science. The wearer is fitted into the full-body suit—worn over clothing—and additionally uses a special pair of crutches. Once upright, the exoskeleton user initiates a step forward with a lateral weight shift, and battery-powered motors drive or assist the legs, replacing neuromuscular function for people with complete paralysis or aiding people with some residual function. The rehabilitative exoskeletons were patterned after an earlier (2008) military version called the Human Universal Load Carrier, or HULC, developed by Ekso Bionics (then Berkeley Bionics) with a research grant from the Defense Advanced Research Projects Agency (DARPA) of the U.S. Department of Defense. With an exoskeleton and a trained therapist, a person can go from a lifetime strapped to a wheelchair to up and walking in only a few minutes.

For Paul Thacker, who hadn't walked in seven months, the experience was amazing. "I'm so competitive, the first time I used the exoskeleton I saw it as a challenge to learn to walk better and faster. I immediately wanted to push the boundaries of what the machine could do," he says. "I continue to believe unconditionally that one day I'll be walking under my own power, but until then I can rehab with the Ekso [short for Ekso Bionics, the type he uses], and it's a magnificent piece of mechanics. It's a powerful symbol of what's possible."

Never a quitter, Thacker has kept competing. In 2013, Polaris built him a special seat for his snowmobile, and he strapped into it and competed in the 2013 Winter X Games SnoCross Adaptive. He competes again this month, in Aspen, Colorado, at this year's Winter X Games event.

Manufacturers of exoskeletons (currently there are at least three companies with functional "exos"—Ekso Bionics, ReWalk and Rex Bionics) and scientific researchers say that exos have many measurable and verifiable rehabilitative benefits. Standing and walking in the suits provides increased circulation, decreased

edema (swelling), and improved urinary and bowel function. At rehabilitation centers across the country, exoskeletons are being used to treat individuals with incomplete or complete spinal cord injury, neurological disease and other forms of lower-limb paralysis due to multiple sclerosis, Parkinson's disease and stroke. Says Michael Firestone, spinal cord injury lead physical therapist at James A. Haley Veterans' Hospital in Tampa, Florida: "Exoskeletons create improved cardiovascular capacity, a decrease in lower-extremity spasms, fewer urinary tract infections, and—with the variable-assist software update—improved strength for incomplete-spinal-cord-injury users. An exoskeleton also motivates patients who have been injured for awhile to get back in shape so they can be a candidate to use the device."

> World adventurer Erik Weihenmayer has parachuted out of airplanes, solo paraglided, scuba dived, skied black-diamond runs, and climbed to the peaks of all of the world's fabled Seven Summits, including Mount Everest. And, incidentally, he's totally blind.

Perhaps most important, says Firestone, exoskeletons provide people with hope for the future. "They see what the exoskeleton does now and where they think it will go in the future to become a part of their everyday lives," he says.

Firestone has worked with eight patients since November 2012, and he finds the technology very impressive, integrating the processor, software and motors to create a functional gait pattern. The advances are progressing quickly, he says. "The next generations will be smaller, more user-friendly and able to handle various terrains."

For distinguished U.S. military special-ops veteran Gary Linfoot (Chief Warrant Officer 5, Ret.), an Ekso Bionics exoskeleton is becoming a regular part of life. Injured in 2008 during his 19th tour in Iraq, Linfoot became paralyzed below the waist in a helicopter accident. Now he has become the first military veteran to receive an exoskeleton (the Ekso Bionics version) for personal use. Suits such as this are currently very expensive (around $100,000 each); Linfoot's exoskeleton was donated to him through a grant made possible by the Infinite Hero Foundation and the Airpower Foundation. On Veterans Day 2013, after more than five years in a wheelchair, Linfoot appeared on the *Today* show on NBC, walking proudly next to his wife in his exoskeleton. Later in the day he walked around the Statue of Liberty in a stirring display of courage and patriotism. Says Linfoot: "It was a great honor to be able to walk by the Statue of Liberty, which is such a symbol of freedom and hope, a symbol of opportunity. That's also what the exoskeleton is; it represents the same things. I wanted to illustrate to other injured veterans not to give up. When people see me walking in the suit, they are awestruck that it's even possible. Hopefully, they'll be inspired by the possibilities."

Linfoot certainly hasn't given up. In 2011 he participated in the Ride 2 Recovery 9/11 Challenge (now called the Minuteman Challenge), pedaling a hand-cranked bicycle for eight days over 500 miles. Now Linfoot is adding daily walks in his exoskeleton to his training regimen. "My philosophy is, if you don't use it, you lose it," he says, meaning that you have to maintain what strength and musculature you have. "The plan is to get up and walk in the Ekso every day," he adds. "I'm part of a clinical trial to improve these devices even more, and help one day make them widely available for home use."

Psychologically, exoskeletons are powerful medicine. "When I first stood up, it was amazing," says Linfoot. "My wife, Mari, said, 'Hey, you're 6 feet tall again!' To see my wife eye-to-eye, and hug my children heart-to-heart—it's a feeling I can't even begin to explain."

Goals that Linfoot shares with Ekso Bionics—of continuing to expand the positive impacts of exoskeletons—are in the process of being realized. The bionic suits are currently in some 30 to 40 rehab centers across the country, including the Scripps Memorial Hospital in Encinitas, California, and the Huntington Memorial Hospital in Pasadena.

With highly visible users such as Paul Thacker and Gary Linfoot making great strides in the suits, the technology's developers want to improve capabilities to include safe navigation over undulating terrain and stairs, and to increase awareness and accessibility enough to make home use of exoskeletons a reality for the many who could benefit. That's important. According to Christopher and Dana Reeve Foundation findings from a study that concluded in 2008, nearly 5.6 million Americans—one in 50—were living with some degree of paralysis. So the technology has potential to help many people.

Sensory Augmentation for the Visually Impaired

It's October 2013. A kayaker paddles furiously down the raging whitewater of the Marañón River, a major tributary of the Amazon River that cuts through the Peruvian Andes. River wash roils over him as he approaches a massive rapid. Disoriented in the giant waves, he flips over in his kayak and disappears, completely upside-down as he descends the "Grand Canyon of South America." A few moments later, he has pulled off a perfect Eskimo roll, righted himself, and made it safely through a maze of massive rocks to an eddy below the rapids. He paddles ashore to rest and regroup. There are many more dangerous rapids ahead.

He is kayaker and world adventurer Erik Weihenmayer. He's parachuted out of airplanes, solo paraglided, scuba dived, skied black-diamond runs, and climbed to the peaks of all of the world's fabled Seven Summits, including Mount Everest. And, incidentally, he's totally blind.

Erik Weihenmayer, now 45, suffered retinoschisis as a child and became completely blind by the age of 13. Despite this

ROB RAKER

Erik Weihenmayer uses a BrainPort device to find climbing holds. The device converts light captured by a mounted camera into electrical impulses that stimulate the user's tongue.

challenge, he has refused to let his blindness prevent him from living an adventurous, exhilarating life. Along the way, he has experimented with various adaptive technologies to help himself, and others, achieve their goals.

In 2008 he tested a technology created by Wisconsin-based Wicab Inc. called the BrainPort device: a headset camera linked to a tongue-depressorlike array, which converts light into electrical impulses that stimulate the tongue instead of the retina. The device, which is not yet cleared by the U.S. Food and Drug Administration for sale in the United States, translates digital information from the video camera into gentle electrical stimulation patterns felt on the tongue's surface through the depressor array. Users feel the patterns on their tongues, and they learn to interpret different sizes, shapes and even motion of objects in the environment they view. The BrainPort assistive device can help people who are totally blind with orientation, general mobility, object identification and even reading a sign consisting of a word or two.

The BrainPort device allowed Weihenmayer to rock climb in a new and different way. Whereas he normally climbs up rock faces or climbing walls by a technique he calls "scanning and groping"—moving his palms across the surface—with the BrainPort device, he could actually perceive climbing holds on the wall 2 or 3 feet above him, allowing him to save energy by reducing his time spent scanning and groping.

Always willing to try something new, Weihenmayer is also currently collaborating with a Boulder, Colorado, inventor named Nate DeVault who has created a visual "augmentation device" called the VISOR (Visual Information Sensory Optical Reflector). The device consists of eyeglasses worn by the blind or visually impaired that, as DeVault puts it, "take visual information and replace it with sound, resulting in a virtual kind of vision." The VISOR captures visual information in full color and three dimensions up to 20 feet away, then converts the information into a sound landscape that transmits as vibrations through small speakers that rest on the user's cheekbones. DeVault explains that the VISOR "interprets the world in the way that people normally understand it, and conveys that information via sound vibrations to signal the brain in the way light impulses would otherwise

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FROM PAGE 75 do." The VISOR wearer effectively converts the sound vibrations back into visual images in his or her brain. VISOR wearers may be able to perceive their immediate environment, identify complex objects and navigate naturally day or night without additional aids such as canes or seeing-eye dogs.

"It's not on the market quite yet," says Weihenmayer, "but the technology and the implications for the blind are exciting." The VISOR gives wearers the ability to read and recognize objects in front of them, and could be used in the future by the elderly or others with limited vision.

Meanwhile, as the VISOR technology is developing, Weihenmayer and his No Barriers organization are dedicated to pushing forward adaptive technologies that allow people with adversities to redefine what's possible. Weihenmayer leads by example. He has been using an auditory adaptive technology to help him prepare to achieve his goal of a solo kayak trip down 277 miles of the Grand Canyon's roiling Colorado River whitewater in September 2014. Weihenmayer is using a special, customized, submersible BlueWave radio and headset system called Neptune BlueWave, designed in the United Kingdom by DS Neptune Developments. The system features cordless helmet-to-helmet intercoms using hands-free, voice-activated Bluetooth technology. The system works like this: Weihenmayer paddles his own kayak, with an expert paddler—a "line setter"—just in front of him choosing the best route through dangerous boulders and waves up to 20 feet tall. Right behind Weihenmayer is his paddling guide, who barks out commands—for how Weihenmayer can follow the line setter—into a mouthpiece transmitter that Weihenmayer can hear in his headset.

Plunging headlong down the river, Weihenmayer hears the command and must react instantly. The commands are simple but crucial, and they use just three basic turns. "Small left!" or "Small right!" calls for a 15-degree turn. "Right!" or "Left!" is a 45-degree turn. "Hard left!" or "Hard right!" is 90 degrees. So far, the technology works. Erik and his team have done practice runs on the Usumacinta River between Guatemala and Chiapas, Mexico; a trial run down much of the Grand Canyon; and the harrowing trip down the Marañón in Peru. For Weihenmayer, who finds solo whitewater kayaking "the scariest thing I've ever done—and I've done some pretty scary things," the adaptive radio technology enables a world of possibilities.

We are living in a time of unprecedented technological advancement, and with these advances being applied to adaptive medical fields, there is a new level of hope for millions of people. With innovation and the will of pioneers such as Hugh Herr, Paul Thacker, Gary Linfoot, Erik Weihenmayer and many others, the very idea of what it means to have a disability is being redefined and re-envisioned. ▲

WSU English professor Buddy Levy is a book author and journalist from Idaho. His next book, Geronimo: Leadership Strategies of an American Warrior *(co-authored with WSU football head coach Mike Leach) will be published in May.*