▶ *FASTER HIGHER STRONGER*

The Cybathlon is a cyborg Olympics that will help disabled people to navigate the most difficult course of all: the everyday world.

BY SARA REARDON

Vance Bergeron was once an amateur cyclist who rode 7,000 kilometres per year — much of it on steep climbs in the Alps. But in February 2013, as the 50-year-old chemical engineer was biking to work at the École Normale Supérieure in Lyons, France, he was hit by a car. The impact sent him flying through the air and onto his head, breaking his neck. When he woke, he learnt that he would never again move his legs on his own, and would have only limited use of his arms.

Confined to bed for months while his body did what healing it could, Bergeron began to look for a way back to cycling. He started to study neuroscience, with an emphasis on research into robotic prostheses that could turn people like him into ‘cyborgs’: combinations of human and machine. He learnt that some of these prostheses used a technique known as functional electrical stimulation (FES) to deliver electrical signals to atrophied limbs or the stumps of missing ones, causing the muscles to contract and restoring some function.

As soon as Bergeron had recovered enough to use a wheelchair, he took that idea back to the lab, where he switched his research focus to neuroscience. Using himself as a guinea pig, he and his team worked out how to stimulate

the nerves in his legs so that his muscles would flex and pedal a bike. “I have become my own research project and it’s a win-win,” he says.

Even with regular exercise sessions to build muscle, Bergeron’s artificially stimulated legs have produced at most 20 watts of power, barely one-tenth of the 150–200 watts produced by an average cyclist. But he and his team are building the FES controller and electrodes into a carbon-fibre recumbent tricycle that he hopes will help him to do better — and perhaps win a medal on 8 October, when he takes his machine to Zurich, Switzerland, to race against other FES cyclists in the Cybathlon: the first cyborg Olympics.

MACHINE LEARNING

Around the world, nearly 80 research groups in 25 countries are honing their technologies for the €5-million (US\$5.5-million) event. They range from small, ad hoc teams to the world’s largest manufacturers of advanced prostheses, and comprise about 300 scientists, engineers, support staff and competitors: disabled people who will each compete in one of six events that will challenge their ability to tackle the chores of daily life. A race for prosthetic-arm users will be won by the first cyborg to complete tasks including preparing a meal and hanging clothes on a line. A powered-wheelchair race will test

how well participants can navigate everyday obstacles such as bumps and stairs.

The venue — Zurich’s 7,600-spectator ice-hockey stadium — should combine with the presence of television cameras and team jerseys to give the Cybathlon a sporting vibe similar to that of the Paralympics, in which disabled athletes compete using wheelchairs, running blades and other assistive technologies. The difference is that the Paralympics celebrates exclusively human performance: athletes must use commercially available devices that run on muscle power alone. But the Cybathlon honours technology and innovation. Its champions will use powered prostheses, often straight out of the lab, and are called pilots rather than athletes. The hope is that devices trialled in the games will accelerate technology development and eventually be used by people around the world.

The everyday tasks being tested in the Cybathlon are much more difficult than they seem, says Robert Riener, a biomedical engineer at the Swiss Federal Institute of Technology in Zurich and creator of the Cybathlon. “I think that people are spoiled by the Internet and Hollywood movies,” he says. “We want to show people there are still challenges.”

Riener traces the origins of the Cybathlon back to news accounts of a charity event: in

Pilot Matt Standridge will compete in the Cybathlon using an exoskeleton designed to help people with paraplegia to walk.

November 2012, a man called Zac Vawter, who had lost a leg in a motorcycle accident, used an experimental, motorized prosthetic leg to climb the 103 storeys of Willis Tower in Chicago, Illinois, in just 45 minutes.

The feat impressed the media — and Riener. But it also frustrated him: Vawter's device, along with similarly impressive prostheses from Riener's lab and others around the world, were not reaching people who needed them. "We're doing great work but not selling it well," he thought. So why not take inspiration from the Willis Tower stunt, and draw attention to the technology through a competition open to everyone in the prosthetics-research community?

Riener's 30-person lab team was excited about designing such an event. And before long, word had spread to colleagues around the world.

At first, Riener had considered hosting showy events such as climbing a mountain on prosthetic limbs. But he changed his mind in 2013, after talking to an acquaintance who had lost an arm to cancer and wore a prosthesis. The device ended in a hook that was moved by cables when the man flexed certain muscles in his stump. It worked well enough for large movements, but was hopeless for fine control. Once, the man told Riener, he had been

buying cinema tickets, and could feel the people queuing behind him staring and growing impatient as he struggled to draw out his wallet and grasp the pieces of paper.

These mundane challenges, Riener realized, were greater and more meaningful than the need to design, say, a spring-like leg that simply helps someone to run fast. So he decided that most of the Cybathlon competitions would be distinctly non-Olympian.

BRAIN POWER

Easily the strangest will be the brain-computer interface (BCI) race, which will feature 15 pilots sitting still for 4 minutes while large screens in the arena show what is going on in their heads. Each will attempt to guide an on-screen character through an obstacle course using specific patterns of brain activity, translated by an electrode cap into three commands: accelerate, jump over spikes or roll under laser rays.

In principle, the patterns can be anything. At the University of Essex in Colchester, UK, for instance, a team of current and former students led by postdoc Ana Matran-Fernandez has designed an algorithm that associates the three motions with a pilot thinking of his or her hand or foot, or working through a maths equation.

The electrical signals are weak, and each

individual is different, so it can be difficult to distinguish between the commands — especially when a pilot is distracted, for example by cheering and adrenaline in the competition. Constantly thinking about tasks is mentally exhausting, says neuroscientist José del R. Millán of the Swiss Federal Institute of Technology in Lausanne, whose team is working on ways to predict thought patterns to make the association more natural and let the pilot relax.

BCIs will probably never be used for real jumping and running, because detecting electrical activity in muscles is much easier. But if such devices could be made cheap and accurate enough, they could help disabled people to guide wheelchairs, cursors or even Skype-enabled robots that would let them participate virtually in an event. "The fact that you can develop this in the lab and bring it out and see it works means there's a future," says Matran-Fernandez.

Other Cybathlon events will highlight the great strides being made with more-conventional devices. In the prosthetic-leg race, competitors must get past obstacles such as stairs, randomly placed stones, tilted pavements and doors — not to mention sitting down in a chair and standing up again. Several participants will be using state-of-the-art smart knees and ankles that can detect force and acceleration as

they walk, and correct their motion if they start to fall.

But even the most advanced engineering pales beside what the intact body does naturally. When a person picks up a pen with a flesh and blood arm, their brain and peripheral nervous system coordinate how far to reach, how to bend each joint in each finger into a precise shape, and how hard to grasp — all without conscious effort. Standard movable prostheses, such as the type with the hook and cables, require the user to do all of this consciously. This takes a great effort, which is one reason many amputees choose not to wear them.

To get around that, researchers have to create computer algorithms that decode signals from muscles and nerves and predict what a wearer is trying to do. In Burnaby, Canada, a Cybathlon team called MASS Impact is working with pilot Danny Letain, a former Canadian Paralympic skier who lost his left arm in a 1980 railway accident. The team has built an arm with a panel of flat buttons that sits on Letain's arm stump.

Using his memory of a hand, Letain imagines making one of 11 gestures, such as pointing. The muscles in his stump then compress the buttons and tell his artificial hand to do what he intends. Letain was pleased to find that the brain circuitry that once controlled his fingers is still in working order, long after he stopped feeling any 'phantom pain' in his lost arm. "I'm using something I haven't used in 35 years," he says.

Some arms are even more advanced. A team led by biomedical engineer Max Ortiz Catalan at Chalmers University of Technology in Gothenburg, Sweden, has developed a two-way prosthetic hand that can feel as well as move (M. Ortiz-Catalan *et al. Sci. Transl. Med.* **6**, 257re6; 2014). The arm is permanently implanted in the wearer's bone, and uses up to nine electrodes to convey motor commands from the remaining muscles to the prosthesis, and to send signals from sensors in the fingers back to the arm's sensory nerves. Cybathlon pilot Magnus Niska is the only person in the world who wears such a prosthesis outside the lab. Ortiz Catalan hopes that the ability to feel objects will give Niska a competitive advantage.

A team led by Ronald Triolo, a biomedical engineer at Case Western Reserve University in Cleveland, Ohio, has a similar strategy for the FES cycling event, in which contestants with spinal-cord injuries will pedal for 750 metres around a circular track. Many of the competitors, including Bergeron, use electrodes on the skin to stimulate the leg muscles. But the Cleveland system — originally designed to allow people with lower-limb paralysis to walk with the help of crutches — features electrodes surgically implanted in the leg muscles. Using an external device, the wearer chooses a

Functional electrical stimulation helps people with spinal injuries race bikes.

menu option, such as 'sit'. An implanted pulse generator activates the electrodes that cause the muscles to contract in the correct order.

After Triolo heard about the Cybathlon, he realized that he could add cycling to his volunteers' exercise regimes. His team has equipped a recumbent tricycle with sensors that detect the angle of the cyclist's leg as he or she pedals, and automatically change the stimulation patterns so that one leg pushes while the other pulls.

Triolo says that all 27 of the people implanted with his electrodes want to try cycling. After putting them through qualifying trials, he is down to a few finalists for the Cybathlon. "We want to go to Switzerland and win this thing," he says. "Then I'd like to use that as a springboard to build an exercise programme here."

EYES ON THE PRIZE

This competitiveness is a far cry from Triolo's initial reaction to the Cybathlon, which was that the competition was a foolish idea. "We should find a way to collaborate internationally on these problems rather than compete," he recalls saying — something that he and Riener say they still hear from some in the prosthetics field.

Triolo eventually came around: he decided that the Cybathlon would at least be a good learning experience. Riener himself hopes that bringing the competition into the open will spur creativity better than the conventional academic process, which is hampered by researchers' concerns about their intellectual property and competitiveness for grants.

Karim Lakhani, an economist who studies innovation at the Harvard Business School in Boston, Massachusetts, notes that competitions also force researchers to finish their work quickly and eliminate doubts about feasibility that prevent them from starting in the first place. He points to the self-driving car, which languished in development for decades until 2005, when the US Defense Advanced Research Projects Agency held a race with a \$2-million prize. The contest eventually drew interest from Google, which is now testing such cars on

the roads. "This contest will serve the same way," says Lakhani. The Cybathlon will not award monetary prizes, just medals. But his research suggests that the recognition enjoyed by the winners could be just as motivating (K. J. Boudreau *et al. RAND J. Econ.* **47**, 140–165; 2016).

Perhaps the greatest advantage of prizes is that they give unknown contestants an opportunity to compete alongside big, well-known players, says Lakhani. The Cybathlon has drawn plenty of both. Otto Bock HealthCare, a multibillion-euro company based in Duderstadt, Germany, and the world's largest manufacturer of prosthetic limbs, has entered three Cybathlon events.

One is the powered-exoskeleton race, in which contestants with spinal injuries will use an external support system to navigate obstacles similar to those in the powered-leg race. Otto Bock's pilot, Lucia Kurs, lost the use of her legs to spinal tumours. Now in her 60s, she can walk 12 kilometres using the firm's commercial leg brace, which has sensors, electronics and motors to guide the knees and ankles through a normal leg swing.

"We're showing off, and checking out other manufacturers" at the Cybathlon, says Christof Küspert, a product manager at Otto Bock. But he says the company is also interested in learning about innovative prototypes from dark-horse developers at universities.

One smaller developer is Jesús Tamez-Duque, managing director of the start-up INDI Engineering and Design in Monterrey, Mexico, who is entering a prototype for an exoskeleton much cheaper than Otto Bock's US\$75,000 model. The device's joints are moved by wind-screen-wiper motors, and much of the body is 3D printed. INDI's competitor uses a joystick attached to his crutches to choose from several programmed movements, such as climbing stairs or sitting.

Tamez-Duque hopes that the Cybathlon will attract collaborators and prove that Mexico can be a player in the field. "The way we see it, the Cybathlon is a competition that concentrates the top-notch robotics labs in the world," he says. "We're still working on getting that representation so that other people believe we can actually add value to them."

The Cybathlon will be back in 2020, as a seven-day event in Tokyo, coinciding with the Olympics. It will have new events for competitors with visual impairments, and will conduct some races outside the stadium. But for competitors in the first Cybathlon, being at the cutting edge is already a thrill. "This is *Iron Man*, this is *Avatar*," says Bergeron. "It's a combination of BCI and exoskeletons all over the place." ■

Sara Reardon is a staff reporter for Nature in Washington DC.