# Exoskeleton Crew

**When 23-year-old Floridian Zachary Smith took on his grandfather in a game of ping pong last December, it was no small personal triumph. Smith, who has Duchenne muscular dystrophy and uses a wheelchair, had been losing strength in his arms for several years and was straining to perform even simple tasks.**

"Eating started to become challenging and I was struggling to brush my hair and teeth — the basic stuff people can do," he recounts. "I want to be more independent. Rather than ask my parents and sister, I want to do more things on my own."

With the support of an exoskeleton attached to his upper body and under the watchful eye of biomedical engineer Madeline Corrigan Ph.D. '17, Smith was able to resist gravity again and again: grilling burgers, shooting a game of pool and playing fetch with his dog. Later this year, he will be the first person to test a motorized version of the exoskeleton, which incorporates technology designed by Corrigan at NJIT – an embedded computer, software, a force sensor and a motor – into the passive, spring-loaded device, developed by Detroit-based Talem Technologies, that he now uses.

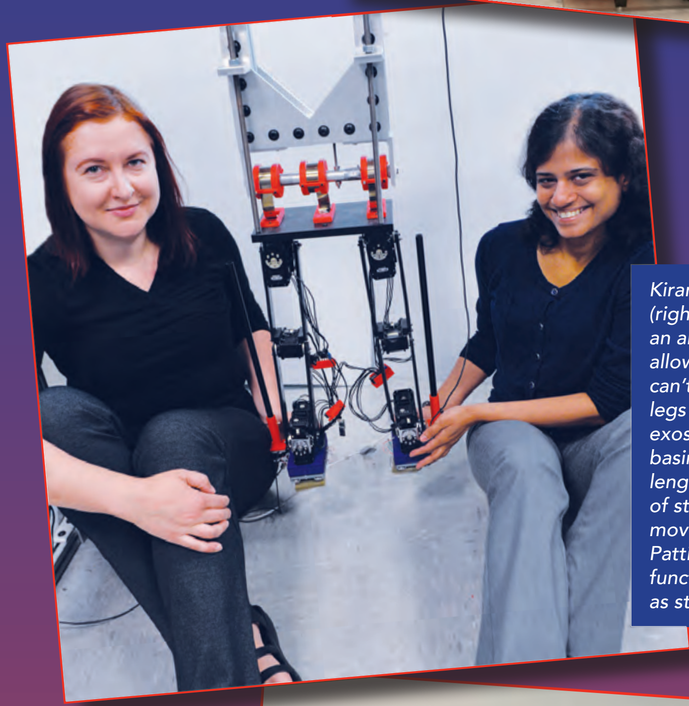
Erick Nunez is working on the ankle portion of an exoskeleton that will allow balance in both directions, compliance to uneven surfaces and a mechanism to make the walking gait more natural.

Corrigan and her collaborators have designed a 30-person beta trial, to launch this year, to test what would be the first device to provide self-directed, motorized assistance to people with Duchenne, allowing them to continue using their arms as their muscles progressively weaken.

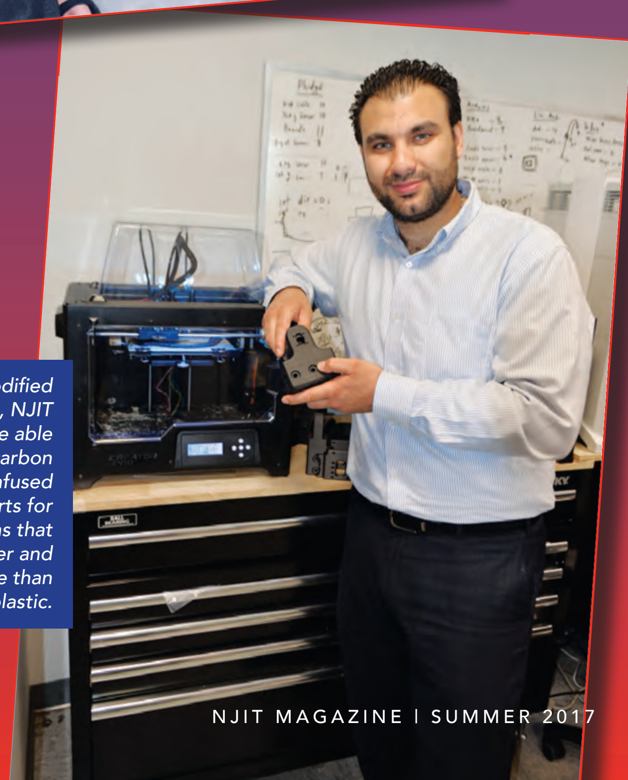
"The exoskeleton operates on admittance control, a robotics-control paradigm in which the motion of the robot is controlled by the magnitude and direction of the force applied by the user's arm," Corrigan explains. "Compared to passive arm supports that require the user to have sufficient strength to move them, admittance-controlled devices significantly minimize friction and inertia, providing more precise compensation against gravity and reducing the exertion necessary to move a limb, particularly vertically."

This operating principle is central to NJIT's growing research hub focused on biomechanics and rehabilitation; researchers in the Department of Biomedical Engineering are now working on upper- and lower-body exoskeletons that incorporate it. They embrace its power to give people with various conditions – Duchenne, cerebral palsy and paralysis from spinal cord injuries and strokes – the ability to plot and execute their own movements, rather than to be controlled by a robot that is programmed to direct and move them.

Richard Foulds, associate professor of biomedical engineering and director of NJIT's Rehabilitation Engineering Research Center, describes admittance control as a rediscovered technology. A couple of decades ago, he recounts,



Kiran Karunakaran (right) developed an algorithm that allows people who can't move their legs to control an exoskeleton by basing stride – the length and height of steps – on hand movements. Irina Pattison is adding functionality, such as stair climbing.



With modified 3D printers, NJIT engineers are able to print carbon fiber-infused nylon parts for exoskeletons that are stiffer and more durable than standard plastic.

PHOTOS: DIANE CUDDY

Ashley Mont is working on an upper-extremity exoskeleton that can be used at home to support the use of a virtual reality-based stroke rehabilitation program for the arm and hand.

Richard Foulds and Ghaith Androwis are building "The Trekker," an exoskeleton with motors that allow movement of the hips, knees and ankles, and embedded sensors that monitor the human-machine interaction.

Madeline Corrigan developed modular robotic-assistance technology based on admittance control that will provide progressive support, from passive to motorized, to people with Duchenne muscular dystrophy, allowing them to use their arms as their muscles weaken.

the rise of autonomous robots favored a competing technology called impedance control that determines position and engineers the torque the motors provide to achieve it.

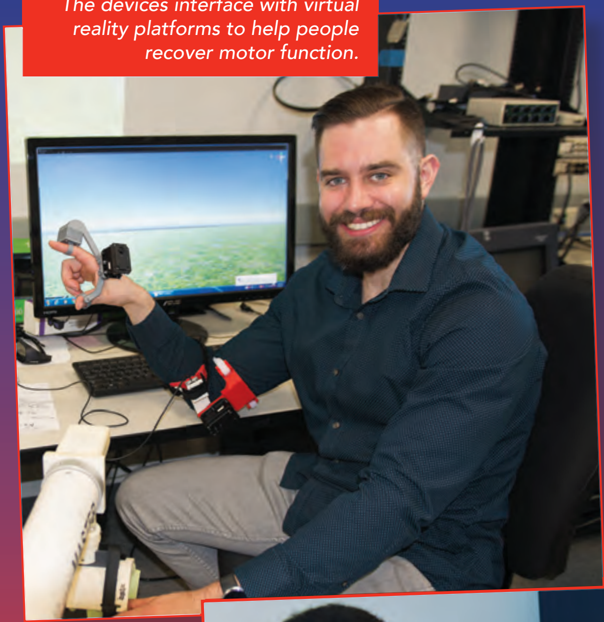
"Impedance control won out and admittance control languished, because engineers at the time weren't thinking about humans and robots operating together," he notes. "Unlike conventional robots that are programmed to move autonomously and may use sensors to engage with the environment, our devices move with the user in an unstructured manner determined by his or her needs. The goal is to have exoskeletons sense the wearer's intentions and to amplify both the strength and range of motion of their upper extremities for reaching and manipulation, while allowing the sensory-motor capability of the arms to substitute for the missing abilities of legs that are either weak or paralyzed. Ideally, we want this to be done in such a transparent way that the person should feel as if there is no robot at all."

To achieve this, the exoskeleton senses the wearer's intention every 1/100th of a second by measuring the forces applied by the person on the device, computing where a virtual mass would move in that short time and signaling the exoskeleton to proceed to that new location. The person wearing the device senses the large, heavy robot as no more than the small virtual mass being moved; its values can be adjusted to amplify strength. The upper-extremity exoskeletons eliminate gravity and friction that impede the movements of weakened arms. The lower-extremity exoskeleton interprets the force and direction signaled by hand motions that mirror the legs' gait.

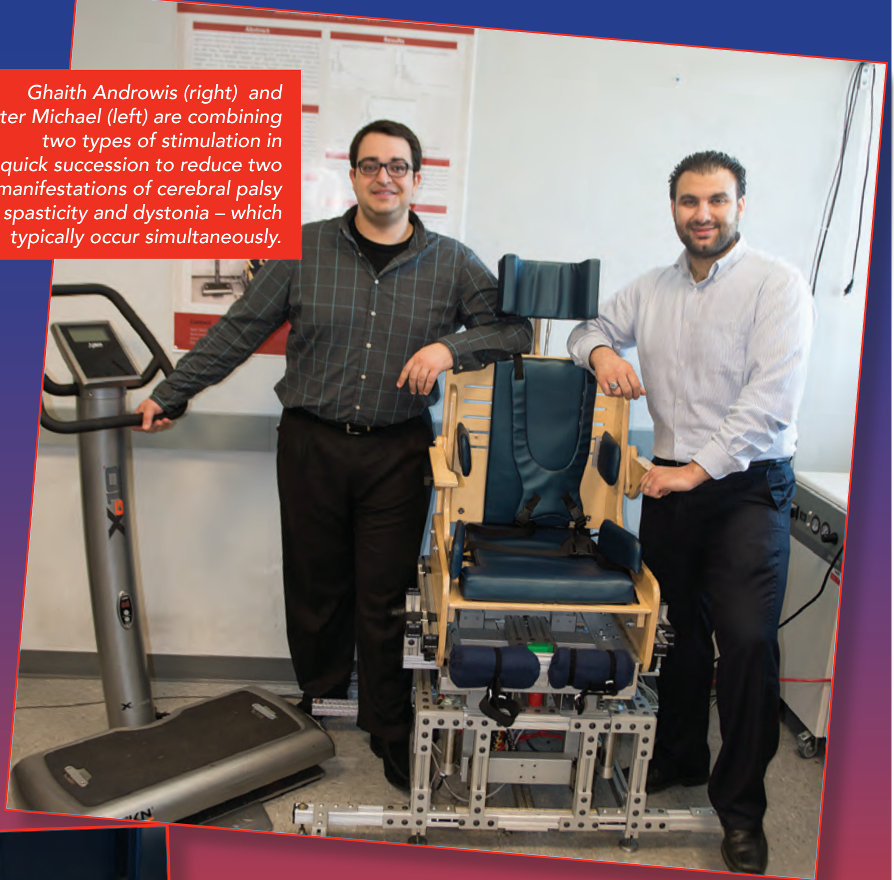
Kiran Karunakaran Ph.D. '16 has developed a half-scale prototype of a wearable robot to be used by people who have lost movement in their legs that bases stride – the length and height of steps – on hand motions.

"We can do this because people can generate similar trajectories using their hands as that of their legs, and by moving the hands, we can prompt the step and replicate that movement, allowing the person to take a more precise stride," says Karunakaran, who recently joined the Kessler Foundation as a post-doctoral fellow. "We are still learning what can be done and what can't with our current prototype – there is a big learning curve – but we think that the overall technique using hands to determine gait is going to work."

Ghaith Androwis Ph.D. '14, an associate research scientist at Kessler and an adjunct professor at NJIT, is working with Foulds to build an exoskeleton with motors that allows movement of the hips, knees and ankles, as well as sensors, to monitor the human-machine interaction. Supported by the National Science Foundation, "The Trekker" is a prototype with open mechanical, electrical and computing architecture, allowing NJIT and collaborators to come up with creative new control strategies using onboard sensors and new actuators to meet the



Kevin Abbruzzese created assistive devices for stroke rehabilitation of the upper extremity which include a wrist exoskeleton and a gripper. The devices interface with virtual reality platforms to help people recover motor function.



Ghaith Androwis (right) and Peter Michael (left) are combining two types of stimulation in quick succession to reduce two manifestations of cerebral palsy – spasticity and dystonia – which typically occur simultaneously.

Oyindamola Owoeye is working on a glove with sensors that will improve the coordination between hands and feet in a lower-limb exoskeleton directed by hand movements.

needs of people with a range of disabilities. A full-scale version of Karunakaran's hand-walking prototype will be the first such device to use the Trekker.

Several graduate students are currently working with Foulds to refine these technologies. Doctoral student Oyindamola Owoeye, for example, is developing a glove with sensors that will help steady walkers by detecting imbalances in their stride through connected foot sensors.

In a related project, Sergei Adamovich, professor of biomedical engineering, is collaborating with Kessler Foundation researchers, faculty from the Rutgers University Department of Rehabilitation and Movement Sciences and NJIT students to extend their earlier work linking robotic exoskeletons with virtual reality platforms to improve neurorehabilitation therapy for people with limited arm movement caused by a stroke. They are developing an exoskeleton that can be used at home.

Kessler Foundation and NJIT are currently developing several new applications for wearable robotic exoskeleton devices with a $5 million federal grant from the National Institute on Disability, Independent Living and Rehabilitation Research, for which Adamovich is co-principal investigator. The team is also evaluating the efficacy of existing robots for restoring and expanding mobility to upper and lower extremities.

Researchers at NJIT have developed a device to prepare people for therapy that will allow them to potentially use these exoskeletons.

Androwis several years ago devised a novel method for decreasing muscle contractions in children with cerebral palsy (CP) by targeting a nerve pathway that bypasses the brain and mechanically stimulating the vestibular system of the inner ear, which senses vertical acceleration and alters muscle tone accordingly. Through controlled oscillations, his chair device has been shown to reduce CP symptoms such as spasticity.

"If their muscles are too rigid, they can be injured during robotic therapy," notes Peter Michael, a Ph.D. candidate who is refining the technology by adding another dimension: whole body vibration via a standing platform, to decrease rigidity. "We're hoping to open up a 20-minute window for treatment that would be unavailable otherwise." ■

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