Defense One

The Cyborg Medicine of Tomorrow Is Inside the Veteran of Today

By Patrick Tucker

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Super strong mechanical appendages and brain implants are common fixtures of a science-fictional future. More and more, American veterans are arriving at that future before the rest of us. As a result of military-funded programs, vets are becoming the research platform for cybernetic technologies that are decades beyond commercial state of the art and that could one day elevate humanity beyond its natural biological limitations.

The idea of improving humanity through technology is older than Icarus, but in recent decades, thanks in part to the rapid pace technological advancement, it's also become an active area of philosophical debate, sometimes referred to as transhumanism. Futurist and technological ethicist Nick Bostrom defines transhumanism as a movement that seeks to understand and evaluate "opportunities for enhancing the human condition and the human organism opened up by the advancement of technology."

It's the word *enhance* that makes transhumanism a controversial subject, suggesting that nature, especially as it applies to the "human organism," can be improved through meddling. The very idea immediately conjures up images of cyborgian super humans that are, as Obi Wan Kenobi once described Darth Vader "more machine... than man."

What is enhancement? More than a decade ago, bio-ethicist Eric Thomas Juengst put forward a definition that many in the field continue to cite to this day. Enhancement seeks to "to improve performance, appearance, or capability besides what is necessary to achieve, sustain or restore health."

To understand the role that Iraq and Afghanistan war vets could play the growing debate over enhancement, and the future of medical devices more broadly, you have to go back to 2006.

Inventor Dean Kamen, creator of such products as the Segway, was at his lab in New Hampshire when he received a visit from Col. Geoffrey Ling with the Defense Advanced Research Projects Agency, DARPA. The agency wanted a new prosthetic arm for wounded veterans returning from combat in Iraq and Afghanistan, where roadside bomb attacks were sending hundreds of troops home without arms or legs. As of December 2013, the number of Americans who had lost an arm or leg in combat in Iraq or Afghanistan was 1,558, according to the Congressional Research Service.

At the time, little changed from was available in World War II. The standard prosthetic remedy for arm amputee consisted of a ball and hook apparatus with no electronic components. What Ling was proposing was decades ahead of the state of the art. He wanted an arm that could restore to a near natural state upper extremity control. It had to be powerful enough to enable the wearer to lift everyday objects but precise enough

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Kamen was incredulous. "I told him he was crazy," he recalled to *Defense One*. In response, Ling pivoted to a direct emotional appeal. "He told me, 'You need to know, a couple hundred of these young people have lost an arm but a couple of dozen have lost two." I went home that night, I was rolling in bed, I couldn't sleep, and I was thinking, 'How do you roll around without arms?'"

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DARPA, too, didn't actually know if the effort would bear fruit. "We never know for sure if an idea is going to come to reality," DARPA program manager Dr. Justin Sanchez told *Defense One*. "We say 'look, we know that in this space there is a set of design properties or qualities that we ultimately want to achieve. We say 'who is really going to come to the table and show that we can do this?' That's really how we get those remarkable things done. We had to completely invent something new in that domain."

The field of robotics had plenty of examples of industrial, medical even humanoid robotic arms that provided illustration of what was possible, but none were in a form factor that Sanchez could use for human patients. The challenge was significantly more complex than simply shrinking down the actuators and other components and then slapping a robot arm on an amputee.

"We knew that the kinds of injuries that people sustain are extremely diverse. People that have sustained pure amputation have one set of conditions. People that sustained a nervous system injury have another set of constraints. Because of that diversity, we needed to come up with an arm system that was also very flexible," said Sanchez.

Kamen took a field trip to different university-affiliated research labs. There, he found that the best minds at work on the problem were dedicated to a largely academic exploration of brain signals, not the arm itself. "The sad truth is that while there was lot of neuro research happening, there was nothing going on to make the hardware for it to run."

Kamen wound up taking on the challenge. In 2007, his company, DEKA Research and Development, received an $18 million grant from DARPA as part of the first portion of the Revolutionizing Prosthetics program. The resulting product, an arm Kamen calls "Luke" after the reluctant amputee hero of the *Star Wars* franchise, was a robotic device that could be steered without a neural interface.

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Some aspects of the noninvasive steering scheme are still fairly sophisticated, such as electromyography, which records electrical activity in skeletal muscles. Others are more straightforward, like wireless radio foot-pedals. "It's a special wireless controller that's worn on the top of the shoe and it turns your foot into a joystick. You turn your foot forward backward left and right and you can wear up to two of them," Tom Doyon, the manager of the project for DEKA told *Defense One*.

"The arm today can be controlled via a variety of modalities," Sanchez explains. "There can be inertial sensors placed on the body and you use physical movement to actuate the arm. The arm can be interfaced with your muscles, so as you twitch and contract your muscles you can use that to control the arm system...it's more

about the variety of conditions that people sustain and then trying to come up with technologies that will meet or exceed what those needs are. The arm has been designed exactly with those properties."

Controlling the arm is like a cross between playing a video game and operating a puppet. The arm features six pre-programed grip patterns. "You have a power grip for grabbing onto a handle. There's a pinching grip," all controlled via the muscles or the feet. "You do have to re-teach your brain that moving the foot can cause the arm to move," Doyon said. In those six grip patterns, there are intermediate stops within the grip for other tasks.

The brain power that runs the arm is simply the human capacity for learning. Doyon says that people can become proficient in tens of hours. "They would train in lab, for two weeks, ten days, at four to six hours a day," he said. After a week and a half of using the arm they were skilled enough to take it home. By the end of the second week they were comfortable enough that they wanted to use the arm in public.

"They won't be pitchers," says Kamen. "They're not going to be able to play the violin. But they can open a door, hold their children; they can do a lot of things without putting deep brain probes in the motor cortex, without subjecting them to more surgical procedures."

In the spring of this year, the third generation of the DEKA arm won FDA approval. It will become the prosthetic limb for amputees and even paraplegics all over the world.

DARPA didn't abandon the neural interface approach to robot appendages. "If you really want near natural control, you've got to go directly into the nervous system in order to interface with that system," says Sanchez. In 2009, they awarded researchers at the Johns Hopkins Applied Physics Lab $34.5 million for the continuation of the Revolutionizing Prosthetics program. The result was the Modular Prosthetic Limb, debuted in 2011, which does demonstrate neural control (but which has not yet received FDA approval.)

In October, a team from Sweden, not affiliated with the U.S. military, demonstrated a robotic arm that is, in fact, mind-controlled and supposedly restores a patient's "sense of touch" according to the researchers. None of that research derails adaption of the Luke arm, according to Doyon.

"As these more advanced controlled schemes are developed, like direct neural control or direct brain control, our arm can be used with those because we have such a flexible control scheme," he said. Researchers at the University of Pittsburgh, currently doing work on neural prosthetic interfaces, are working on advancing neural interfaces using the DEKA arm, among other tools.

DARPA is championing a menagerie of neuroscience-driven, cybernetics programs related to restoring veterans to normal life. There's the Hand Proprioception and Touch Interfaces (HAPTIX) program, which seeks to further advance neural-interface controlled schemes and the Electrical Prescriptions (ElectRx) program, which "will explore modulating the body's peripheral nervous system to help regulate biological responses to infection, injury, and other imbalances," according to Sanchez.

The military is looking to build brain chips to restore memories to soldiers through a program called Restoring Active Memory (RAM). Within the next four years, the agency wants a prototype to demonstrate that memories can be restored, via the device, after 14 days. If the RAM device works, it could potentially go on to revolutionize treatment for memory loss.

Military Applications for Prosthetics Research?

It's all feel-good work that virtually any American can support, and does, though the Obama administration's Brain Initiative, a multi-year effort funneling money to a variety of public and private institutions, also including the NIH, the FDA and IARPA.

But DARPA is still a military agency, tasked with creating "strategic surprise." Given the agency's mission, its natural to wonder if the agency's cybernetic research may be tied to some military application—beyond just restoring health to injured vets. Could chips that "restore" memory one day lead to a device that enhances memory for soldiers? Does Luke and machines like it forecast a future of SEAL teams with super-strong, mind-controlled limbs and preternatural abilities of recall? More broadly, at what point does therapeutic research to restore normal brain and body functioning become research into enhancement?

The subject of human soldier enhancement is fraught with ethical concerns, as bioethicist Patrick Lin a documented in this white paper on the subject. Among the questions that the government would have to consider before officially undertaking any research related to this: Is the proposed enhancement safe? Would it be permanent? Would soldiers be allowed to opt-out on the basis of religious concerns, etc.? Lin makes a compelling argument that enhanced soldiers could be considered weapons and may be considered illegal by international arms control bodies.

On this count, DARPA emphasizes that they aren't pursuing biological enhancement with programs like Revolutionizing Prosthetics or any of the current programs related to neuroscience, even if enhancement could theoretically create a military advantage.

While they are a military agency, they maintain that their current portfolio of neuroscience programs doesn't constitute "military" research in an operational sense. The agency views their neuroscience work as foundational to build new neurotechnologies and advance the field more generally. "Most of the time we put forward specific objectives (e.g., a neural prosthetic) to focus research and address a defined need, but with the understanding that there are many levels of breakthrough research and milestones that have to be achieved first to get there, which is why DARPA structures its programs in phases," a DARPA spokesperson told *Defense One* in an email. "Within the defense applications, as a first priority, DARPA is interested in using the knowledge to better understand and mitigate threats to the brain, such as from traumatic brain injury and its effects."

While DARPA is clear that the agency is not interested in biological enhancement research, it has funded a variety of projects that, to the casual observer, border on enhancement exploration, as Noah Shachtman points out in this 2007 article for *Wired*. Those include giving soldiers enhanced energy (via quercetin and B vitamins), improved performance when sleep deprived (through transcranial magnetic stimulation) and the ability to digest cellulose.

Other branches of the military have conducted their own research into what the military has taken to euphemistically calling "performance optimization" such as the Army's Comprehensive Soldier Fitness Program.

Pushing aside ethical considerations, the rapid development of devices like the Luke arm begs the question of what is technologically possible? The answer: more than you might think. Kamen sees some superhuman attributes making their way into next-generation models of the Luke arm.

"We will move to the point where the arm—while still not having the sensitivity, dexterity, feel, and fine control of a good human hand—it may soon have a stronger, tighter grip. It will be like having a monkey wrench attached to the end of your elbow. Or it might be able to move fast enough to act like certain types of tools, even punch through things. It could also, obviously, pick up things that are hot or cold and not do physiological damage," Kamen said. "The next-generation will probably start to have some functionality beyond that which nature had, not in all categories and in many, many ways it won't be as good as nature, but it may have some capabilities that nature doesn't have."

On this, DARPA maintains that the agency's "role in development of the DEKA Arm System is complete; we defer to DEKA regarding any plans for possible upgrades to the technology."

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But if the intention of DARPA, in advancing the field of prosthetics, is not to create a battlefield advantage, why not leave this research to pharmaceutical and medical supply companies? Sanchez says it's a simple matter of "paying back the debt" to wounded veterans. Thanks to $300 million newly available to research institutions like DARPA through the president's Brain Initiative, there's plenty more money for that repayment.

But there's a supply and demand issue as well. The market for creating cybernetic prosthetics is simply too small, the research too expensive, and any potential return on investment too far into the future to attract traditional commercial players.

"Where is the technology going to come from for these ...orphan medical products? The answer is the military. Because we, as a culture, have always felt that the people who have literally given their arms and their legs for this county deserve whatever we can give them back," said Kamen.

Republicans and Democrats can't agree on the role the government should play in funding speculative medical science, except when the recipient group is veterans. In this way, even in our national efforts to "give back" to the veteran community, we are asking one final favor from them, to serve as participants in a grand experiment to advance futuristic implants and prosthetics. One day, if we do achieve the enhancement of the human organism, it will be thanks in no small part to veterans who are trying out these technologies today.

"The fact is, the one thing about the question of who deserves what when it comes to medical care, that's easy to answer. We, as a society, have an unwritten pledge to soldiers that says, in return for what we asked them to do for us, we will do whatever is possible for them. That is the reason why the military has always funded the next generation technologies in medicine, since the civil war," said Kamen. "The ultimate beneficiary always turns out to be the public."

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