Statement to the Subcommittee on Research and Technology

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Chairman Bucshon, Congressman Lipinski, and Members of the Subcommittee. Thank you for inviting me to provide my views on the revolution in prosthetics. I will provide you my opinions and a short demonstration of what technology can provide for those who have lost a limb. The opinions stated are my own and do not necessarily reflect those of the Johns Hopkins University Applied Physics Laboratory or the Department of Defense.

The Defense Advanced Research Projects Agency initiated the Revolutionizing Prosthetics program in 2005 to provide expanded prosthetic options for Warriors who experienced traumatic upper-extremity amputations during contingency operations in Iraq and Afghanistan. After APL was awarded its contract to support the Revolutionizing Prosthetics program in 2006, we learned that many upper extremity amputees chose to either wear a body-powered split-hook or no prosthesis at all. The split-hook technology, which has not changed much since it was patented in 1912, and the other prosthetic arm components available in 2006, offered very little natural arm and hand function. Our task at APL was to develop a neurally-integrated yet modular anthropomorphic arm system with near-natural control. Today, I am happy to report we have met that challenge and have prototype systems that are providing great hope to people with arm amputations and to those that have lost the ability to control their limbs due to spinal cord injury, stroke, or neuro-degenerative diseases.

In addition to support from DARPA, we have been fortunate to collaborate with several government agencies, including the National Institutes of Health, Walter Reed National Military Medical Center, Uniformed Services University of the Health Sciences, Veterans Health Administration, US Army Medical Research and Materiel

Command and the Food and Drug Administration. This collaboration has been integral to the success of the dedicated team led by the Johns Hopkins University Applied Physics Laboratory and comprised of researchers from the Johns Hopkins University, the California Institute of Technology, the University of Southern California, Rancho Los Amigos National Rehabilitation Center, the University of Pittsburgh, the University of Pittsburgh Medical Center, the University of Chicago, Northwestern University, Hunter Defense Technologies, Blackrock Microsystems, and the University of Utah.

Our team strove to accomplish four major goals. First, we developed a prosthetic arm that was able to mimic the natural arm. The Modular Prosthetic Limb (MPL) is capable of articulating 26 joints, enabling it to do almost anything the natural arm can do. Unlike most current prostheses, the MPL is a completely integrated system that can be separated into three modules, full-shoulder, humeral or radial configuration; each including the wrist joint and hand. The MPL can be easily adapted for use with conventional body attachments. Many users have stated that the natural motion of the MPL is an extremely important aspect of the MPL resulting in a feeling of embodiment.

Our second objective was to provide a means for the user to naturally control the arm. To attain this level of control, the APL team initially explored peripheral nerve control options and showed that interfacing with muscles and nerves in the residual arm of research participants with an amputation allows them to achieve remarkable functional improvements with prostheses. Since 2010, we have focused on direct brain interfaces that have demonstrated amazing control capabilities for our research participants with tetraplegia. Magnetic resonance imaging (MRI) studies show that even years after an amputation or onset of paralysis, the areas of the cortex associated with motor control are still activated by the thought of moving a lost limb. The team's challenge was to access and interpret these brain signals in a way that would enable the research participant to move the MPL as they would move their natural arm.

Third, we are seeking to restore natural sensation via sensors on the prosthetic limb. The ability to perceive physical interactions with objects and sense the position of our natural limb without seeing it allows us to walk into a dark room and not fall or to reach into a handbag and grasp an object without seeing it. Just like the brain remembers how to move a lost limb, research suggests the areas of the brain involved in perceiving sensation are still active and capable of perceiving sensation. While much less is known about generating sensory perception, we do know that stimulation of sensory nerves years after an amputation can produce vivid sensations that are associated with the missing limb. Rehabilitative surgeries, such as Targeted Muscle Reinnervation (TMR), have provided the ability to stimulate peripheral nerves in residual limbs based on inputs from the MPL hand sensors; amputees have stated they can feel sensations in their phantom fingers as a result of these stimulations. In addition, research participants have stated they experience great relief from phantom limb pain after their TMR surgeries. With over 100 embedded sensors in the MPL, we have only begun to explore the possibilities of restoring lost perception and the sense of touch.

The final goal was to create a foundation of achievements that could be leveraged into future efforts to advance the capabilities of neuroprosthetics for the benefit of people with unique rehabilitation and restoration needs. This required a systems approach to integrating advances across multiple disciplines including: neuroscience, neurosurgery, biomedical engineering, electrical engineering, and mechanical engineering. It was through the systematic integration of all these advances that we were able to translate neuroprosthetic technologies into practical applications that met the Revolutionizing Prosthetics program goal of functional restoration.

During the course of the Revolutionizing Prosthetics program, we have made significant advances and learned important lessons. We developed advanced algorithms that can decode a paralyzed person's intent to move their arm and hand from their neural brain signals. As a result, research participants have the ability to move the MPL in a very intuitive way, often stating that they are just thinking about moving their own arm or simply thinking about manipulation of a target object. This control extends to the ability to form multiple grasps, an achievement that realizes the goal of dexterous prosthetic arm and hand control. Our TMR efforts have provided neurosurgery insights that include the benefit of preserving the nerves in the residual limb to provide the possibility of using signals from those nerves to control prostheses and provide sensory feedback to the user. These new surgical approaches could eliminate the need for secondary surgeries to address phantom pain. Another important advance was the development of miniature motors. Customized motors in the joints of the MPL allow for near-natural movements and deliver the high torque required for human-like strength in a small lightweight package.

In addition to advancing these engineering and clinical capabilities, APL created a virtual reality version of the MPL for use when a physical limb system is not available. The Virtual Integration Environment (VIE) is completely interchangeable with the MPL, providing the research community with a low cost means of testing brain computer interfaces. The VIE is being used to test novel neural interface methods, study phantom limb pain, and serves as a portable training system. We have already provided the VIE to multiple research groups at universities across the United States at no cost. By extending this open platform approach we can stimulate other research teams and foster increased interdisciplinary collaboration.

It is my experience that the technologies developed under the DARPA Revolutionizing Prosthetics program have had a profound positive impact on the research participants. Whether due to amputation or a spinal cord injury, users of the MPL system have had very positive reactions to being able to move a limb for the first time since their injury or illness. We have seen individuals with limb loss - often years after their injury - learn to move the prosthetic arm in minutes. Johnny Matheny, who lost his arm to cancer, underwent TMR surgery and tells of being able to feel his hand again and about relief from phantom limb pain. Air Force Technical

Sergeant Joe Deslauriers, lost both legs and his left arm in Afghanistan, and has demonstrated how advanced control algorithms enhanced his ability to use a prosthetic arm. Research participants with paralysis have been able to physically interact with others via the MPL driven by their brain signals. For the first time in the seven years since his accident, Tim Hemmes, an individual with tetraplegia, was able to hold his girlfriend's hand using the MPL. Similarly, Jan Scheurmann was able to feed herself without assistance for the first time in over ten years using the MPL. These, and other research participants, have become integral members of the team; and their bravery and dedication is an inspiration to the rest of the research team.

While the team has accomplished much since 2006, many opportunities lie ahead of us to provide greater independence and quality of life to people with disabilities and the elderly. By using advanced algorithms to control robotic devices, I believe we can significantly reduce cognitive burden for those using assistive devices to accomplish everyday tasks. I believe it is essential to continue efforts to develop neuroprosthetic devices that will allow for natural control of replacement limbs. While today we are focused on research participants with amputations and paralysis, the insights we are gaining promise to help the elderly and those that suffer from amyotrophic lateral sclerosis (ALS), stroke, multiple sclerosis, and traumatic brain injury. Finally, I feel it is important for these efforts to lead to the development of a clinical standard of care that is viable for transition to the home and workplace, enabling individuals with disability to lead more productive and independent lives.

Again, Mr. Chairman, thank you for this opportunity to inform Congress on the practical benefits that are coming out of the long-term Federally-funded research on advanced prosthetics and related fields, and I look forward to answering your questions.