Computation combats concussion damage

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Reuben Kraft works on computational simulations of the human brain that can help diagnose concussions, as well as on designing artificial nerve bundles to reverse concussion damage. Credit: Sarah Kim

As football season rolls on, fans across the country look forward every weekend to touchdowns, tackles and tailgating. But recent news about football-induced brain injuries is casting a pall on the sport.

One researcher in Penn State's Institute for CyberScience (ICS) is working to reduce the risk of these injuries—and to reverse the damage they cause—through the power of high-performance computing.

Reuben Kraft is an assistant professor in the Department of Mechanical and Nuclear Engineering and the Department of Biomedical Engineering, and is an ICS co-hire. He specializes in constructing computer models of the human brain that may help to diagnose brain injuries by simulating head impacts.

"These simulations are so important because it's very hard to investigate brain injury experimentally—we can't just hit people on the head and see what happens," said Kraft. "Computer simulation is the only way to investigate injuries of this nature."

Kraft's goal is to prevent brain damage to athletes in football and other contact sports.

"Big-time sports programs have lots of athletic trainers who can diagnose concussions, but think about all the smaller colleges, high schools and youth programs with no athletic trainers on the sideline," said Kraft. "Athletes in those programs who have concussions might not be diagnosed and could get back in the game, risking further damage. We're trying to protect them."

High-impact simulations

To create accurate brain models, Kraft's team combines many different equations, each one describing a physical property of one of the many kinds of matter in and around the brain.

"We have equations for how everything behaves—skin, skull, the fluid between the brain and the skull, different kinds of brain tissue, even brain fibers," said Kraft. "We combine these with equations that account for the geometry of the brain."

Kraft's team then uses the brain models to simulate injuries, determining the specific effects of different kinds of head trauma by changing variables such as the force and angle of impact. They are working to ensure the simulations are accurate by comparing their results against MRIs of actual injured athletes.

Kraft is combining his simulations with biomechanical sensors worn by athletes to provide real-time diagnoses of brain injuries. When a football player takes a hit to the head, the sensors would collect data about the force and location of the impact and send it to a high-performance computer system running Kraft's brain models. The models would then simulate the results of the hit based on the data to determine which parts of the brain are likely to be injured and the severity of the damage.

This information would be generated in moments, and would be sent to the player's coach, who could make sure the player stops playing and gets necessary treatment. The diagnosis would also be sent to the player's parents and doctor.

These diagnoses are crucial because in many sports programs, coaches rely on players to self-report if they have suffered a concussion. A player who has sustained a big hit might not be aware of the damage caused, or might avoid self-reporting to stay in the game.

Kraft aims to partner with an education company that promotes awareness of the risks of brain injury to high school athletes. By combining a curriculum about brain injury for students and coaches with tools for diagnosing brain damage, Kraft hopes to reduce sports-related brain injuries and make athletes safer.

Growing new nerves

Kraft is applying his computational modeling expertise not just to preventing brain injury but also to counteracting its effects. He is collaborating on a project to build artificial living nerve bundles called Micro-Tissue Engineered Neural Networks, or micro-TENNs. These micro-TENNs could be used to replace damaged cells in the brain.

"This is a big deal," said Kraft. "We're talking about restoring lost brain function, not just for reversing concussion-related damage but potentially for treating strokes and brain diseases."

By modeling the properties of different micro-TENN materials and designs, Kraft predicts which designs will grow rapidly and carry electronic signals effectively. These predictions are then tested in the lab by his collaborator, Kacy Cullen, at the University of Pennsylvania.

Kraft hopes that the computational framework his group is developing will save time, as the designers will not need to test designs which are unlikely to be effective.

"The great thing about computational mechanics is that it can be applied in so many ways," said Kraft. "The same techniques I use for simulating brain damage can also be used for designing new materials—from stronger ceramics and glass to brain prosthetics."

Hitting close to home

Kraft's interest in preventing and reversing brain damage began around 2009, when he was working at the U.S. Army Research Laboratory (ARL). There, his research focused on soldiers who had been injured in the wars in Iraq and Afghanistan.

Kraft remains dedicated to helping soldiers who experience brain trauma through his research, as well as victims of domestic violence. But when he left ARL, he expanded his focus to also include sports injuries. The growing controversy over concussions in football made this research area relevant—and it is also a topic in which he has also has a personal stake.

"I was an athlete myself in high school," said Kraft. "I was runner-up in the Maryland state championships in wrestling, and I was an All-American lacrosse player, too. I was never officially diagnosed with a concussion, but I probably had them."

His experiences with potential head injuries have motivated Kraft not just to understand the mechanics of the brain, but to make these insights useful to the general public.

"I want to push our technology to a place where most people can access and use it," said Kraft. "I think over the next 10 years, you'll see brain enhancements and tools for measuring brain function become a much more common part of people's lives."

While Kraft plans to focus on the brain and neurotechnology for the time being, there are many other major challenges in his field to explore. Biomechanics researchers have only begun adopting computational methods relatively recently, and Kraft expects these techniques to lead to many new ways of enhancing the human body.

Wherever the field of biomechanics goes, Kraft will be at the cutting edge of it, applying his computational expertise and drive to improve the lives of the people around him.

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