CAN THERAPY

An engineer and a video game

John Vito d'Antonio-Bertagnolli recalls the precise moment his research project – a device to correct an eye-movement disorder – collided momentously with the real world. He was describing it to a prospective applicant at an open house, when the student surprised him by asking, "Is it possible to see it?"

After watching him don an Oculus Rift headset and fend off animated bugs attacking in 3D on his computer screen, seemingly with his eyes alone, the student revealed, "I had this exact problem when I was younger, and my therapy felt like such a chore. This could have really helped me." He'd struggled with schoolwork – and reading in particular, he'd confided.

"I'd never met anyone affected by the disorder," recounts d'Antonio-Bertagnolli, a senior at the time, majoring in biomedical engineering. He'd been working on the device for weeks, sometimes playing the role of control, or normal-sighted person, and admits he'd found it repetitious and somewhat abstract. "It put a

EYE BE FUN?

DESIGNER TAKE UP THE CHALLENGE

human face to everything we were working on. Meeting him – and making that connection – became a big motivator."

A year later, he is still a member of the vision therapy team – now as a master's student – who has played a central role in the device's development. Critically, he and another student, Robert Gioia '17, helped secure a $10,000 Engineering Projects in Communities (EPIC) grant from IEEE, the international engineering organization, to radically redesign it. Working with Gioia, a video game designer, under the guidance of the project leaders, an NJIT professor and her clinical partners, the two students have converted what was once a room-sized instrument into a computer-based virtual reality (VR) game they hope will spark both interest – and self-discipline – in youngsters with the disorder.

The device has grabbed the attention of prominent eye therapists around the country who will soon test it in children's hospitals from Philadelphia to Birmingham to Boston. What has everyone excited is its potential to revolutionize vision therapy by allowing people to improve their vision at home.

EYES THAT REFUSE TO PLAY AS A TEAM

The project began taking shape several years ago when Tara Alvarez, a professor of biomedical engineering who studied convergence – coordination between the eyes as they turn inward to focus on a near object –

An NJIT team of researchers is studying various visual cues to the convergence system using a custom-engineered Oculus Rift virtual reality headset.

became interested in people whose eyes wouldn't cooperate. Because each eye sees the image separately, they experience double and blurred vision and have difficulty concentrating. Before even thinking about correcting the problem, known as convergence insufficiency (CI), however, she first had to figure out how to measure it.

"We started developing an instrument that could detect subtle, but significant differences in how eyes track near objects. We are studying various visual cues to the convergence system using a custom-engineered instrument we built with funds from a National Science Foundation (NSF) development grant. Our device measures disparity – the ability to see images as unitary – and accommodation – the ability to see images clearly. We measure the speed and accuracy of eye movements quantitatively," she explains. "This is an important advance, because the differences in motion, while significant, cannot be evaluated through qualitative observations, simply by looking closely. And you can't buy an instrument off the shelf to do it."

Convergence insufficiency affects about five percent of children and adults, about 12 million people in the U.S., who report significant problems when reading or doing close work. For children, the disruption caused by losing their place on a page, difficulty finishing assignments and, more generally, diminished concentration, can have a devastating impact on schoolwork. About 50 percent of people who've suffered a concussion or blast injury and 35 percent of people who have had a stroke have been found to have CI and also manifest symptoms for varying periods of time.

"You begin to question your own abilities and this can lead you to make important decisions about what you can – or can't – do in life," says Mitchell Scheiman, dean of research at Salus University, who has studied the problem for 25 years. He is a co-investigator with Alvarez on a five-year National Institutes of Health (NIH) grant to understand the underlying neural mechanism by which vision therapy leads to a sustained reduction in visual symptoms in people with CI. "Several of the symptoms and behaviors associated with CI are related to attention, similar to those reported in children and adults with attention deficit hyperactivity disorder (ADHD)."

He added, "I'm an example myself. When I was 10 I had an undiagnosed condition and was having difficulties at school. I couldn't read comfortably. I went from one eye doctor to the next and was told nothing was wrong, because they didn't test for CI. School nurses don't identify the problem either because it doesn't register when children are asked to look at the eye chart. They are able to read the letters clearly."

While most people can be successfully treated if the problem is correctly identified, Scheiman and Alvarez say, there aren't enough doctors who provide the therapy. Studies led by Dr. Scheiman have shown that current home-based therapy is no more effective than placebo therapy and is therefore not recommended as a primary treatment option. Some clinicians speculate that a reason for the poorer results is that unsupervised patients don't comply.

ENTER THE ENGINEERS

To measure CI, Alvarez first adapted a haploscope, a multi-part instrument that uses mirrors to send each of the eyes an image separately to see how well they converge – meet by crossing – to see a single one. It is covered in a voluminous black tent, and users must brace their chin on a stiff bar to keep still. It succeeds as a diagnostic device, but is too large, immobile and monotonous to replicate at home.

"We needed to boost motivation by making the therapy fun," says Alvarez, who chose the Oculus Rift, a virtual reality headset she learned about from students, as an ideal technology. "I was in search of a team to run with it." She knew d'Antonio-Bertagnolli, a student ambassador for the department, who loved robotics. She sought out Marc Sequeira '02, coordinator of Game Development for the IT Program of the Ying Wu College of Computing, and he suggested Gioia, who is "an excellent coder and an artist as well."

The new team encountered its first challenge within the hour. The application for a provost's undergraduate research grant to fund Gioia's part in the project was due the next day and he knew almost nothing about it. Sequeira says he wasn't worried. "Rob is one of the strongest students in the history of NJIT's game development program. I was confident that he would get the award, which he did."

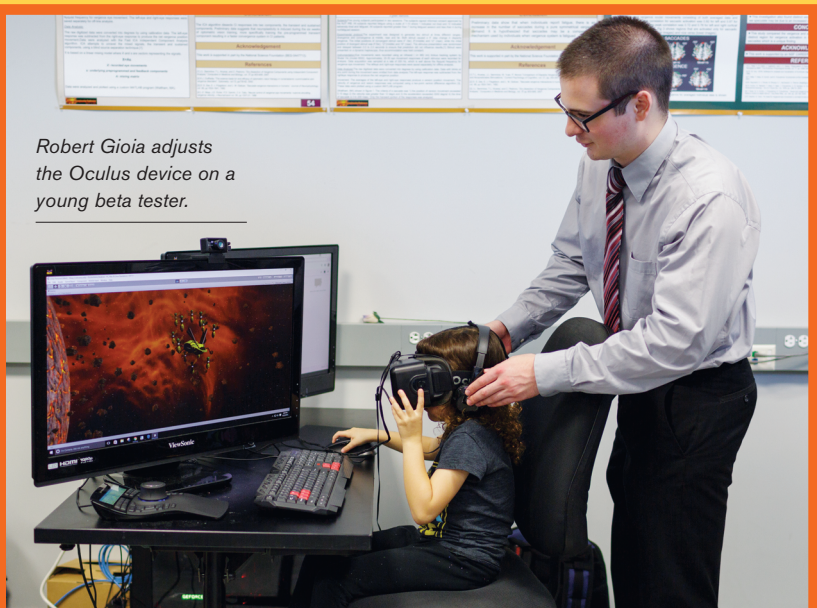
Soon after, the team faced an even stiffer challenge in the form of a milestone development decision. Should they pay a company to build the device they were designing – or build it themselves?

"The eye-tracking device we had was the size of a dorm room, but we needed it to fit in a hand," d'Antonio-Bertagnolli recounts. "We estimated it would cost $10,000 to shrink it. We decided to do it ourselves, aiming to spend less than $500." And so at the end of that summer, at the urging of Newark College of Engineering Dean Moshe Kam, he and Gioia applied for an EPICS grant from IEEE to pay for the parts.

"This was a whole different experience convincing strangers to back us on something we hadn't done yet," d'Antonio-Bertagnolli recalled. Once again, they prevailed.

MAKING THERAPY FUN!

The game is played by the eyes, while a hidden camera measures their movements. As their technical advisor, Alvarez instructed them to make sure the infrared light used to track eye movements stayed within safety limits so patients don't burn their eyes. She asked them to include a Gabor patch, a fuzzy image that cannot be kept in focus, in many of the 3D gaming objects, because



Robert Gioia adjusts the Oculus device on a young beta tester.

it stimulates disparity vergence, the ability to see images as unitary. Another key criterion was to ensure that 3D objects approach patients along the midline, in line with their nose, so their eyes are crossing equal distances.

"The core requirement was that an object had to move toward the person playing. To succeed at zapping it, they need to stare at it, converging their eyes correctly. But it also had to be entertaining," Gioia recounts. "So John and I put our heads together and came up with the idea of classic arcade games like Galaga, a two-dimensional shooter game. I designed a game with insect-based flying ships coming at the player in 3D that we named Bug Eyez. Using their eyes, the players would launch missiles to defend themselves."

Gioia said he factored in parents' concerns about violence. "There are no guns or blood, but the spaceships do explode on contact with the missiles, so it's still exciting," he notes. "To address any further concerns parents may have about violence in the game, there will be an option accessible from the game's main menu allowing the player to toggle the explosions on and off, so younger children will be able to play a version of the game where enemy ships simply disappear on impact with the missile."

The team is building a database that captures eye movements as well as the amount of time played. "By signing into the database, clinicians will be able to follow their patients' progression remotely as they move through the game," Alvarez explains, adding that players will log in with a username and password corresponding with a unique account identity in the therapist's database.

While he was sketching out the first game, d'Antonio-Bertagnolli started on the hardware.

"The eye-tracking part of my job was simple. The pupil is a hole in the eye that doesn't reflect light, but absorbs it, making it dark and therefore easy to spot and track," he explains. "My challenge was to fit a tiny eye-tracking camera into the space between the lens and the screen of the Oculus – the VR device – so that it could pick up eye signals but would not be seen by the person playing the game. That would be distracting."

He installed a camera into what seemed the easiest spot to insert and remove it. The game became unplayable.

"We were clearly going to have to get much more creative," he recounts. "After installing the cameras the first time, we realized that in mounting it, we had changed the distance between the lens and the screen of the Oculus, making the game appear out-of-focus. So we moved the camera and 3D-printed more and more complicated mounts to hold them in place. We went through about a dozen design iterations until settling on one that worked."

Members of the vision therapy research team include: Robert Gioia '17, Biomedical Engineering Professor Tara Alvarez and John Vito d'Antonio-Bertagnolli.

EDUCATION VS. ENTERTAINMENT

Games can be effective as therapy or a distraction, depending on how well entertaining aspects of the game are balanced with the system's therapeutic requirements, Sequeira notes. Integrating hardware artfully is also critical, he says, because if the peripheral devices players interact with are uncomfortable or cumbersome, they are less likely to use it.

"Therapeutic game design requires close collaboration between game designers, peripheral and hardware developers, and, in this case, neuroscientists, clinicians and therapists. So changes in any one area have to work seamlessly with the others," he says, adding, "The therapeutic game sector hasn't always made great games that people want to play, but this has been changing rapidly. Developers like Rob, with skill sets in programming and design are increasingly able to work with interdisciplinary teams of scientists and clinicians to achieve fantastic results."

Virtual reality, with its integration of immersive environments, sensory feedback and spatial interactivity, is helping them reinvent the genre. Gioia has created several new game scenarios to appeal to different tastes, including air hockey, attacking zombie hordes and a dungeon-crawler version resembling Dungeons and Dragons/Legend of Zelda. For the youngest children, he is designing a firefly "catch-and-release" game and an easy mode for beginning players with tortoises trundling slowly toward them to give the players time to get themselves acquainted with the therapeutic movements.

"We're creating a whole range so everyone has something to play and they can even mix it up for novelty," says Gioia, who adds that he is continuing to make the games more complex. "In the first prototype we built, the player had to keep his head still. But the games we have developed since have a more visually rich, immersive environment the player can look around and enjoy while preparing to battle. This is intended to encourage excitement and maintain player interest."

BETA TEST AND BEYOND

The game has already passed one crucial hurdle. Kids will play it.

In September, Alvarez brought in her two children as "beta testers." Christian, 12, has played the game four times over the course of its evolution, sometimes bringing friends along with him to try it, and even spotted a small glitch once the designers have since corrected. In his recent session, he zapped "20 to 30 bugs" over the course of six minutes and pronounced the game entertaining, noting, "I would definitely play this."

Ari, 6, also gave it a key thumbs-up on visuals. "It's cool how the bugs come close to me." Later this fall, the device will undergo a first major pilot demonstration at The Children's Hospital of Philadelphia (CHOP), where the team will conduct a study of 10 children between the ages of 11 and 17 with CI and compare them with 10 children who participate in conventional therapy.

Christina Master, M.D., a pediatrician and pediatric sports medicine doctor at CHOP who specializes in concussions, will oversee it. As Alvarez and Scheiman, Master says she's eager to better understand the disorder and determine whether a home-based device can treat it. "Many kids don't recognize they have a visual problem. After a concussion, for example, they have difficulty describing the symptoms with any specificity. Sometimes they'll just say, 'I don't feel well. I don't like reading. I get tired,' " she notes. "We had a hunch about what was going on, but we couldn't quite put our finger on it. Assessments for CI are not routinely done. Often, kids would see an ophthalmologist and be told they're normal. Given a specific questionnaire screening for CI, however, they are better able to pinpoint details like trouble reading and skipping lines."

PHOTO: THE CHILDREN'S HOSPITAL OF PHILADELPHIA

The vision device will undergo a first major pilot demonstration at The Children's Hospital of Philadelphia.

Master says that for many years, general pediatrics tended to dismiss CI and related vision disorders, thinking that they didn't warrant treatment.

"In the 90s, it was not a diagnosis that we considered and many kids were left in the gap. But now, because of the work that Dr. Scheiman has done, it's an accepted diagnosis and Dr. Scheiman has shown in elegant multicenter studies, that vision therapy is effective. With my concussion patients, vision therapy often gives them a headache and they really have to work at it. And it's boring. It's clever is to make the exercises a game by using a mind-trick that makes it feel like mental telepathy, as if the child had superpowers. We are excited about the possibilities that this opens up to us in terms of vision therapy for children with CI after concussion."

The team, led by Scheiman and with the participation of five children's hospitals, is looking to study convergence insufficiency related to concussion. Alvarez's role would be to replicate her custom instrumentation at each of the children's hospitals, including the University of Alabama, Birmingham (UAB). An epicenter of football culture, the university is a major hub for head injury and helmet research.

"Helmets still only protect the skull, not the brain," she notes. "Part of what UAB studies is younger children in Pop Warner football, because their injuries are worse than those in the NFL. Kids don't know how to brace."

"We'll have to do a full clinical trial to see if the device works without a vision therapist overseeing it," Scheiman says.

LIFE BEYOND THE LAB

The vision therapy team believes there is a potentially large market for an inexpensive therapy device that can be monitored by a clinician.

"There is essentially no technology in the marketplace to do this. There are just simple devices like colored balls on a string and passive computer exercises, but they don't use eye positions and aren't games by any stretch," d'Antonio-Bertagnolli says.

Since they began redesigning the device, the team has won two grants to begin commercializing it, including an NSF I-Corps grant through NJIT that got them out of the office talking to potential customers and toy businesses. This fall, they won $50,000 in development capital from the New Jersey Health Foundation (NJHF).

"After meeting with Dr. Alvarez to learn about her research, we began to understand that the convergence insufficiency she is addressing can have far-reaching learning repercussions for children with this disorder," explained George F. Heinrich, M.D., vice chair and CEO of the foundation. "We were drawn to the idea that Dr. Alvarez is employing a novel way for a child to participate in his or her own treatment, which could prove to be very effective when treating the disorder."

THE BRAIN IS A BRAVE NEW WORLD

d'Antonio-Bertagnolli once felt the pull of medical school – both his parents are doctors – but now believes he can achieve important therapeutic goals through biomedical engineering. He is particularly enthusiastic about clinical uses for virtual reality.

"The Oculus is just a screen with two lenses in front of it, but what it's able to do is so far-reaching in terms of healing vision – and very possibly more. The more I learn about virtual reality, the more intrigued I am by its capabilities. I think we could eventually use it to help treat other vision disorders, detect concussions and possibly even treat psychological problems like post-traumatic stress disorder," he speculates.

"I don't know how transformational it will be ultimately, but there is so much down the line to look forward to. I think I will continue to be surprised and excited for the rest of my life," he says, adding, "There is such a close-knit BME community at NJIT. None of this would have happened if I weren't here. This was the right place and the right time as this technology takes off."

Last April, he and Gioia received yet another validation of their work when they were awarded the top prize at NJIT's TechQuest contest.

Gioia, who arrived at college knowing he wanted to design games but also to "help people" said he is also enthusiastic about the potential of what he calls "transformational games."

"I'm excited to see where the video game industry goes from here. The genre is so young – as time goes on, we will continue to see additional applications that extend beyond just entertainment," he says, noting that he is thrilled to have already had a chance to explore this territory, "to use my game-design skills to have a positive societal value. I can't wait to see where it goes from here and how this experience will lead me into a career in such an exciting and opportunity-filled field."

Alvarez, who began her academic career as an electrical engineer, says she switched to biomedical engineering in order to have a more direct and tangible impact on clinical therapy.

"Now that I'm working with clinicians like Mitchell and Tina, I'm starting to see that happen. The medical field is expanding and these collaborations allow us to help the masses of patients, not just a handful. We're starting to examine, for example, the number of visual conditions that include improper eye alignment. Our first application is convergence insufficiency, but we have ideas for other eye movement disorders," she says.

Alvarez is also at the forefront of an exciting field of study that brings together engineers, neuroscientists, clinicians and technologists to explore connections among vision, development and cognition.

"There is so much talk about big data, but people don't realize how much information there is in the visual environment that the brain is taking in, interpreting and acting on constantly. The brain is a major communications center," Alvarez notes. Similar to any therapy, the repetitive nature of the vision exercises leads to a sustained reduction in symptoms, suggesting that the brain has rewired or changed in some way."

Alvarez is working with Bharat Biswal, distinguished professor of biomedical engineering, and Xiaobo Li, an associate professor of biomedical engineering, to use functional MRI to understand how the brain changes after therapy.

"Once we understand how it changes eye movements and brain function, we can use that knowledge to design more effective and personalized vision therapies we hope will lead to better outcomes," she says. "Our aim is to help more patients recover more vision function in less time, at a lower cost in the comfort of their own home." ■

Author: Tracey L. Regan is an NJIT Magazine *contributing writer.*