frontiers | Frontiers for Young Minds

HUMAN HEALTH
Published: 21 May 2024
doi: 10.3389/frym.2024.1338446

THE MIND-BENDING WORLD OF NEW BRAIN TECHNOLOGIES

Susan J. Debad [1*], ***Olaf Blanke*** [2] ***and Bruno Herbelin*** [2]

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *Laboratory of Cognitive Neuroscience, Neuro-X Institute, Faculty of Life Sciences, Swiss Federal Institute of Technology (EPFL), Geneva, Switzerland*

YOUNG REVIEWERS:

ELLIOT
AGE: 13

KONSTANTIA
AGE: 10

Our amazing brains allow us to do incredible things, yet they remain mysterious in many ways. Researchers have discovered some situations in which the brain can be "fooled", and these insights into the brain's inner workings have led to some exciting new technologies, including virtual reality (VR). In addition to its well-known role in gaming and entertainment, VR has some amazing uses in the field of medicine. VR can help patients manage pain, and it can also help surgeons practice delicate procedures and guide them during operations. Other advances called brain-machine interfaces can listen to the brain's chatter and translate thoughts into commands for computers or even robotic limbs, which could greatly improve the lives of people with certain disabilities. In this article, we will explain how researchers are using findings from cutting-edge brain research to produce exciting new technologies that can heal or even enhance the brain's functions.

LEARNING ABOUT THE BRAIN BY "TRICKING" IT

Do you like to fool your brain? Many people love things like optical illusions, magic tricks, and other effects that change the way we see reality. Some popular museum exhibits even include distorted rooms that make people appear to grow or shrink as they move around, mirrors that create the illusion of endless corridors, or holographic images that seem to float in space (for examples, see here and here). Beyond a fun type of entertainment, however, studying the ways the brain can be fooled can help researchers understand how this critical organ works and how they can help certain brain problems.

One famous brain-tricking science experiment is called the rubber hand illusion. In this experiment, which you can watch here, a volunteer sits at a table with one of his arms hidden behind a partition, replaced by a fake-looking rubber arm lying on the table in front of him. The scientist gives the same touch cues (gentle stroking with a paint brush) to both the fake and the real hand, which tricks the volunteer's brain into perceiving the fake hand is part of his own body. Suddenly, another experimenter hits or stabs the fake hand, causing the volunteer to jump and react as if his hand were threatened. Do you think *your* brain would be fooled by this experiment? Chances are, it would. But that is not a bad thing, because figuring out how the brain can be "tricked" in this way gives scientists important information, as you will see as you keep reading.

THE AMAZING BRAIN

The brain is an amazing, complex organ. It controls everything we do, from moving and breathing to thinking, feeling, and remembering. It is also the source of our creativity, imagination, and intelligence—important characteristics that help make us who we are.

NEUROSCIENTIST

A scientist who studies the brain and how it helps us think, feel, and do everything we do.

How does one organ do all these things? **Neuroscientists** are still trying to understand exactly how the brain works, and many mysteries remain unsolved. What *is* known is that the brain is made up of billions of cells called neurons, which communicate with each other using electrical and chemical signals. Neurons are connected in intricate networks that form the basis for the brain's functions. We also know that specific areas of the brain are primarily responsible for certain functions, like vision, touch, hearing, movement, and emotions, to name just a few.

All this complexity makes the brain extremely difficult to treat when it gets sick or injured. Problems that originate in the brain can cause pain, memory loss, mood disorders, or movement difficulties. In addition, the brain is extremely delicate and sensitive, so it is not easy for doctors to work on—especially since it is so well-protected by the skull.

Neuroscientists and doctors are working hard to improve their understanding of the brain so that they can develop new ways to help this vital organ heal and improve. One clever way to study something complex is to find its limits. Observing situations in which the brain "fails" or does not work as expected can help scientists to understand how it *normally* functions. For example, in the rubber hand illusion, the brain "fails" at telling a rubber hand apart from its own hand. Investigating how this happens can teach scientists about the way the brain perceives the body. What is more, learnings from such experiments are leading to cool brain-related technologies that can make life better for both doctors and patients.

VIRTUAL REALITY CAN AID BRAIN SURGERY

VIRTUAL REALITY

Advanced technology that puts you inside a computer-generated, 3D world, making it feel like you are in a totally different place.

ROBOTICS

The science of designing and using robots—machines that can be programmed to perform tasks, often mimicking actions of humans, to help make our lives easier.

MINIMALLY INVASIVE SURGERY

Surgery that involves using tiny cuts and specialized tools to fix health problems, causing less pain and quicker recovery compared to traditional surgery.

AVATAR

A virtual representation of oneself in a computer-generated environment.

Have you experienced **virtual reality** (VR)? Maybe you have played computer games using a VR headset or visited a museum featuring an immersive or interactive VR-based exhibit designed to show you the world through the eyes of a certain artist or allow you to examine objects in a virtual collection. VR is a computer-generated 3D environment that you can experience as if you were there. VR can make you feel like you are in another place or world, where you can explore and interact with objects or even other people. There are many exciting applications of VR technology.

For example, neurosurgery is a type of surgery that involves operating on the brain or the nerves. Due to the complexity and fragility of the brain, neurosurgery requires an extremely high degree of skill and lots of training. Neurosurgeons can use VR to view a 3D map of a patient's brain, to help them plan for surgery or to guide them during surgery, so that they know where to cut and how to get to the problem area without damaging healthy brain tissue. VR images can be combined with **robotics**, in what is called robotic-assisted **minimally invasive surgery**. "Minimally invasive" means that the incisions are smaller than those made in "regular" surgery, and it is usually easier for a patient to recover after the operation. In robotic-assisted minimally invasive surgery, the surgeon does not actually touch the patient—the robot has tiny tools and a camera, and the surgeon controls the robot kind of like a tiny drone, by watching a screen and moving specialized controllers that tell the robot exactly what to do. Although the surgeon might be sitting a meter or more away from the patient, VR allows them to feel like they are in another body, or **avatar**, actually operating on the patient. The better the VR technology, the more the avatar will feel like the surgeon's own body as they use the robotic tools, and the more accurate and safer the surgery will be. (To see what robotic-assisted minimally invasive surgery looks like, watch this video or this one.)

Virtual reality can also be used to train doctors as they learn to become surgeons. Practicing delicate surgeries in a VR environment

before attempting them on real patients helps surgeons to have more confidence in themselves and improves their surgical skills [1]. As VR technology continues to improve, more training programs are likely to start using VR to prepare their surgeons for the operating room.

VIRTUAL REALITY CAN HELP MANAGE PAIN

If you *have* experienced VR, you know that it can be very effective at "tricking" the brain—sometimes you can forget where you really are as you fully imagine yourself in the virtual setting. As the rubber hand illusion illustrated, scientists know that the brain can be tricked into thinking a fake hand is their own hand. Could we similarly trick the brain into not feeling pain? Research tells us that the answer is yes! Neuroscientists are finding that VR can help to reduce or control several kinds of pain, including the pain and anxiety patients (even kids!) feel during certain medical procedures. VR may also help patients cope with **chronic pain**, which is pain that often begins with an injury but keeps happening even years after the injury has healed. Managing chronic pain can be extremely challenging, and it is a serious problem because the pain can make it hard for people to do normal activities, like go to work or school, have fun with friends, or even sleep.

CHRONIC PAIN

A type of pain that does not go away, lasting for months or even years, and can affect both the body and emotions, making everyday life challenging.

How exactly does VR help with pain? For one thing, VR is really good at distracting people from their pain by focusing all of their attention on the VR environment. However, the pain-relief effects of VR go beyond distraction. When a person in a VR setting feels strongly that their avatar is their actual body, they switch to perceiving the avatar's body as their body - and feel less pain at their real body. Instead, the person's brain pays attention to the information coming from the avatar. Since the avatar is not feeling pain, the brain "learns" that the body is pain free... and this "lesson" that the brain learned can carry over into reality, when the person stops using VR (Figure 1).

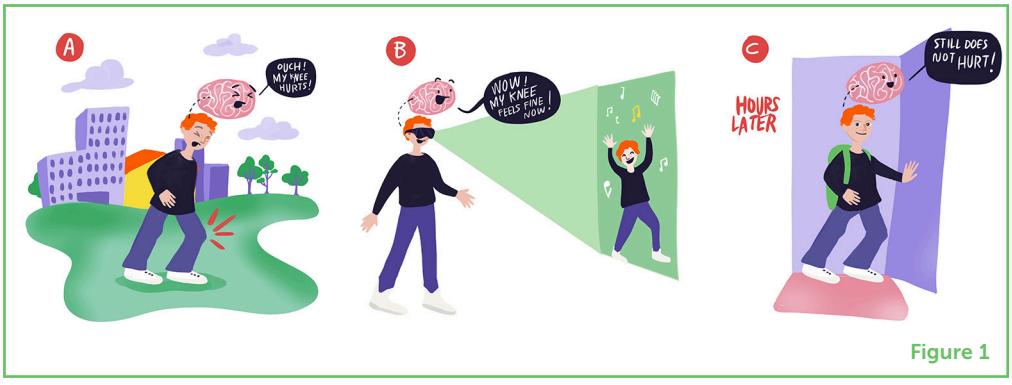

Figure 1

(A) If a person has chronic pain in their leg, for example, the brain pays attention to that pain and "learns" that the leg hurts. **(B)** If the person uses VR that makes them feel strongly that their avatar is their own body, the brain stops paying attention to signals from the actual body and pays attention to signals from the avatar instead. Since the avatar does not have leg pain, the brain "learns" that the leg is pain free. **(C)** The pain-reducing effect of the VR treatment can sometimes last for hours (figure created by carlottacat.com).

While some people have no pain for hours after a VR "treatment", most neuroscientists and doctors agree that VR only temporarily reduces pain—it does not cure it. VR can be used in other ways to help people to cope with their pain, for example by immersing them in peaceful

scenes that make them feel relaxed, or by guiding them through meditations and breathing exercises [2, 3]. One big advantage of some VR-based pain-management technologies is their convenience—if patients have a VR headset, many of these treatments can be done from home.

CONTROLLING MACHINES WITH OUR THOUGHTS?

Beyond VR, there are other cutting-edge technologies being developed to help the brain. Have you ever wondered what it would be like to control a robot with your mind? This might sound like science fiction, but it is possible with **brain-machine interfaces (BMIs)**. BMIs involve technologies that can read brain activity and programs that can translate the brain's messages into commands for computers or robotic devices. Such devices include **neuroprosthetics** designed to replace or restore the function of a missing or damaged body part, like a paralyzed arm. To read the brain's electrical signals, small devices called electrodes are often used. The electrodes are inserted into the brain or attached to the brain's surface. If a person has a neuroprosthetic arm and wants to move it, the electrodes pick up the brain's electrical message from the thought "move arm", and those messages are translated into signals telling the neuroprosthetic arm to move. In addition to helping people with neuroprosthetic limbs move around, eat, and get dressed, for example, BMIs can also be used to help people who have issues hearing, speaking, or even seeing [4].

BRAIN-MACHINE INTERFACE

A direct communication pathway between the brain and an external device, allowing a person to control or communicate with computers or machines using only their brain activity.

NEUROPROSTHETICS

Advanced devices that replace or enhance nerves or brain areas that do not work properly, helping people regain lost abilities like movement or hearing.

A new advance in the field of BMI research involves *flexible* BMIs. Instead of being made of hard, uncomfortable materials, like the chips inside a laptop or phone, flexible BMIs have soft, bendable electrodes that can adapt to the brain's shape and movements, making BMIs more effective, accurate, and comfortable [5]. BMIs are still in the early stages of development, but with further research, they could help make the lives of people with disabilities much easier and help many people to regain their independence. Using BMIs to make normal brain abilities better is another exciting area of research. For example, BMIs could be used to send signals *into* the brain, to boost certain brain functions like movement control, memory, mood, or attention.

THE FUTURE IS MIND BLOWING!

When it comes to new technologies that could help our brains, the future looks bright (Figure 2)! Early research tells us that these technologies hold a lot of promise for everything from training surgeons to improving the lives of people with pain or disabilities. Although more research is needed to make brain-assisting technologies widely usable, scientists are dreaming big. In the future, with the help of these technologies, our brains might have some

cool new "superpowers". We might be able to control machines with our thoughts, virtual reality might help us learn new skills faster and remember more than ever before, and we might find new ways to heal and help the brain in conditions like dementia, depression, or anxiety. Some of these technologies could even help us to understand the mysteries of consciousness. The possibilities for improving health and quality of life are virtually endless—the future of brain tech is going to be mind blowing!

Figure 2

Figure 2

Researchers are working on many promising new technologies that could heal or even improve the brain. These include techniques to help people manage pain and anxiety, neuroprosthetics that can help people with disabilities regain important functions, and systems to train surgeons to perform delicate surgeries, just to name a few. Together, these advances could help many people live happier, healthier lives (figure created by carlottacat.com).

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talk by Olad Blanke.

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SUBMITTED: 15 February 2024; **ACCEPTED:** 06 May 2024;
PUBLISHED ONLINE: 21 May 2024.

EDITOR: Ana Godinho, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Andreas Skiadopoulos and Wendy E. Huddleston

CITATION: Debad SJ, Blanke O and Herbelin B (2024) The Mind-Bending World of New Brain Technologies. Front. Young Minds 12:1338446. doi: 10.3389/frym.2024.1338446

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC. OB is co-founder and shareholder of Metaphysiks Engineering SA and a member of the board and shareholder of Mindmaze SA.
The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ELLIOT, AGE: 13
Elliot is a 13-year-old cello playing soccer player and just earned the rank of Eagle Scout. In his free time he likes to code video games and teach himself math.

KONSTANTIA, AGE: 10
Konstantia is a curious 10-year-old girl who loves reading as much as the next person! Her passion for reading excites her whenever she discovers a good book. Having lived in various places around the globe, she has mastered already three languages. Konstantia adores interacting with other kids. If it were up to her, she would play all day long!

AUTHORS

SUSAN J. DEBAD
Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard". She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan

lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time, she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

OLAF BLANKE

Olaf Blanke is Neuro-X Professor at the Swiss Federal Institute of Technology in Geneva. A medical doctor by training, he combines robotic, digital, and neurobiological methods to understand consciousness and the self. He has studied what happens in the brain when a person feels like they leave their body (a mental state called out-of-body experience); he also studied ghost sensations (such as feeling the presence of another person next to you when there is nobody there). Olaf has developed technologies in his laboratory to cause and investigate such experiences and many other body illusions. In his free time, he enjoys playing basketball, skiing, and reading.

BRUNO HERBELIN

Bruno Herbelin is a senior researcher in virtual reality (VR) and cognitive neuroscience in the laboratory of Prof. Blanke at the Swiss Federal Institute of Technology. He started working with VR in 1997, and his Ph.D. research showed that immersive VR therapy can help people with social phobia. He uses VR in clinical applications to alleviate pain or breathing discomfort, and he is developing a virtual laboratory approach for cognitive neuroscience research. In his free time, he goes to the mountains to climb, hike, or collect mushrooms.