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"MIND-READING" MACHINES

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YOUNG REVIEWERS:

VERDI ELEMENTARY SCHOOL, MS. MEIER'S CLASS

AGES: 10–11

VERDI ELEMENTARY SCHOOL, MS. NALL'S CLASS

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How do we know how the brain works? Doctors cannot open the skull like a jar of candy and close the lid afterward... or can they? In fact, putting electrical wires into human brains has been safely performed for many years. These devices, termed brain-machine interfaces, can help doctors and scientists record electrical signals from the brain, to tell them how the brain interacts with the world. Researchers are using this technique to improve the quality of paralyzed patients' lives and to build brain-controlled game prototypes. Though powerful, brain-machine interfaces still face many challenges. Does this sound like a field that you might want to pursue? Keep reading to find out more!

CAN A MACHINE "READ YOUR MIND?"

NEURONS

Special cells in the body that carry messages between the body and the brain.

Neurons are special cells in the body that carry messages between the body and the brain. For example, when you move your leg, neurons carry the message from your brain to your leg. Without neurons, you would be unable to taste, touch, hear, smell, think, or move your limbs. Neurons only communicate when they are connected. However, neurons may become disconnected due to injury or disease. Imagine if you woke up one day and could not move your legs or arms! Even if you could still think about moving them, moving would not be an option if your neurons were not communicating. You would not even be able to use a wheelchair if your arms were not working. But what if there were a way to use your thoughts to control a wheelchair? Good news! A **brain-machine interface (BMI)** is a device that can "read" the electrical activity in the brain. A BMI can detect signals in the brain and, since it connects with a computer and another device like an electric wheelchair, it can carry out actions the user wants to perform. With the help of BMIs, people with paralysis or amputations can perform everyday tasks and regain some of their independence.

BRAIN-MACHINE INTERFACE

A device, such as an EEG cap, that connects the brain and the computer.

HOW DOES A BMI WORK?

How does a BMI know what direction you want to move your electric wheelchair? Your brain is thinking "move forward," but how does the BMI read your mind? The neurons in your brain talk to one another when you think about moving the wheelchair forward, so the first step is to record those brain signals. We can record brain signals using **electrodes**, which are devices that collect electrical signals. For example, the person in Figure 1 is wearing a special type of electrode-containing cap known as an **electroencephalography (EEG)** cap. Another type of electrode, called an **electrocorticography (ECoG)** grid, is placed directly on the brain's surface. A surgeon must remove the skull to place the ECoG grid, but it does not penetrate the brain—it just sits on the surface. In contrast, **intracortical** (meaning within the brain) electrodes, which look like very tiny needles, are placed deep into the brain tissue, also through surgery. They can record very detailed neural activity. Figure 2 shows these three types of electrodes [1].

ELECTRODE

A tiny piece of metal that can conduct electricity—in this case, the electrical activity of the neurons in the brain.

ELECTROENCE-PHALOGRAPHY (EEG)

A method to measure brain activity using electrodes in a cap that is placed on the head.

ELECTRO-CORTICOGRAPHY (ECOG)

A way to measure brain activity using electrodes that are placed on the brain surface, in structures called ECoG grids.

INTRACORTICAL

Inside the brain.

After recording brain signals with the electrodes, the BMI translates these signals into instructions for the wheelchair. The computer learns the shape of brain signals related to various directions, kind of like learning a new language. However, it takes time to learn this new language, so the computer must study the brain signals to make correct translations. After learning how to translate the signal, the BMI can decide which direction the user wants to move. Electric wheelchairs are not the only devices that can be controlled with a BMI. BMIs can control a mouse cursor on a computer screen, and can close the hand of a robotic arm.

Figure 1

A BMI controlling a wheelchair. Electrical signals from the brain's neurons are recorded using electrodes (here, an EEG cap) while the user thinks about moving the wheelchair in a specific direction. The computer translates the signals into commands that the wheelchair then carries out.

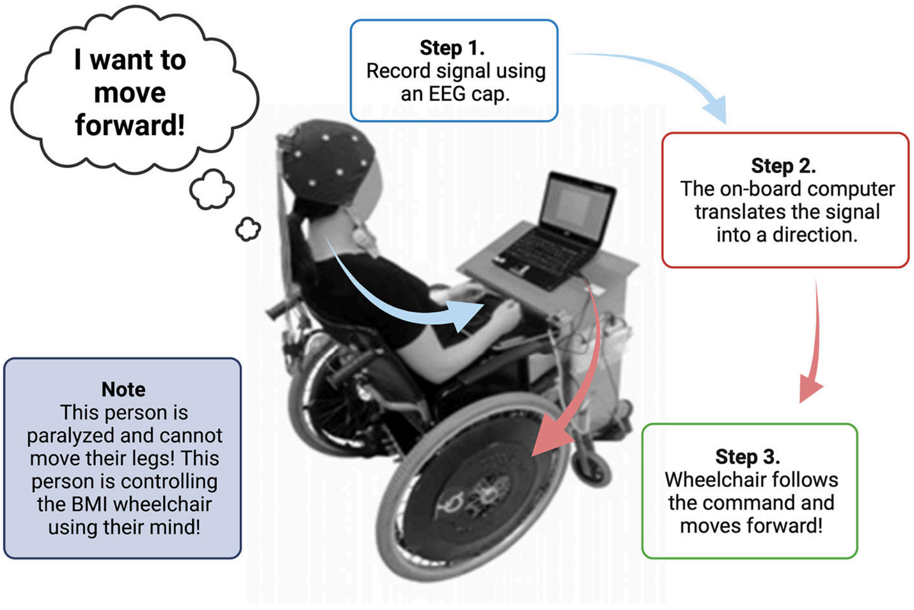

Figure 1

Figure 2

Three types of electrodes and their potential applications. BMI translates the signals recorded from either EEG, ECoG, or intracortical electrodes (Image credit: NeuroNexus), which can be used for both assistive applications (to help people maintain a basic quality of life) and recreational applications (for fun).

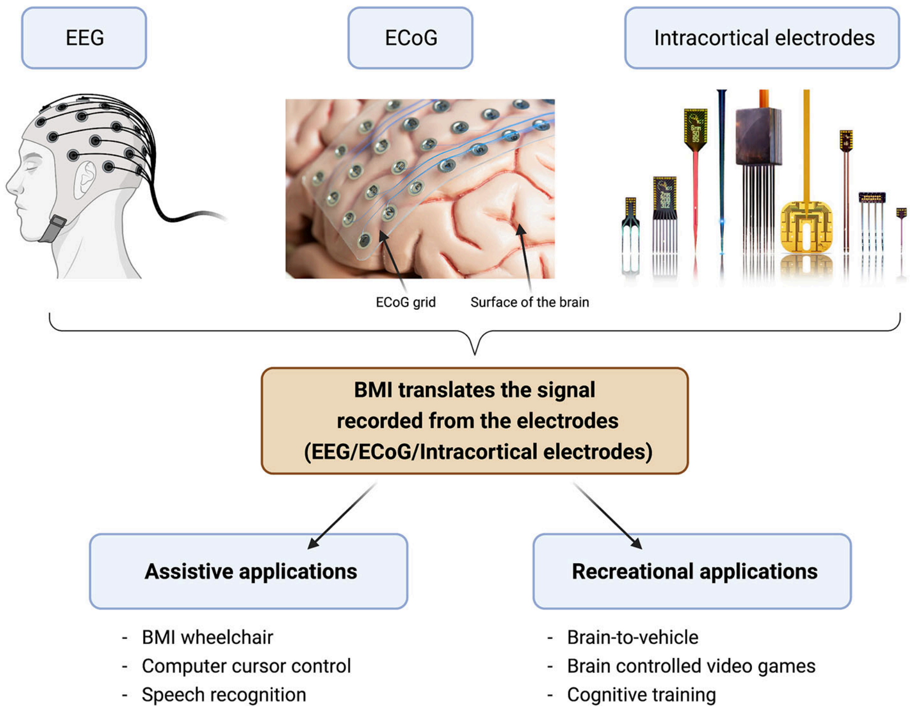

Figure 2

HOW DO WE TEST WHETHER A BMI IS SAFE AND EFFECTIVE?

Doctors and scientists are careful about approving medications and medical devices for human use—that is how patients can be sure the pills they take are safe and effective. It is the same for BMIs, especially those that require surgeries to implant electrodes. Scientists perform many tests before using BMIs on patients, so that safety is the top

CLINICAL TRIAL

After researchers make sure the device or drug is safe, they use human volunteers to test if it is safe and effective.

priority. Before using a BMI on humans, scientists use it on animals such as mice, rats, or monkeys. If the BMI passes those tests, then the next important test is performed, called a **clinical trial**. Clinical trials allow scientists to understand whether BMIs are safe for human use and whether the devices work as designed. For example, scientists test whether the BMI can accurately record the user's brain signals. Scientists also use clinical trials to discover possible side effects—for example, to make sure the electronics do not cause any electrical sparks to the brain. Patients must also be monitored to ensure that no infections arise after surgery. If scientists detect problems during the clinical trial, they fix them to ensure the BMI is safe and useful.

However, clinical trials are not perfect—there may be long-term effects that take years to detect. Moreover, the electronics that make up a BMI can slowly break down over time, and sometimes it can take years for doctors to notice the changes. You can rest assured that any BMI available for purchase or use has undergone a significant number of thorough safety tests. We must also remember that BMI is a *choice*—users have the final say in whether they want to use the device. It is also important to note that the user can control the BMI—the BMI does not control them! A BMI cannot steal a person's thoughts, make them smarter, or make them do something they do not want to do. BMIs only do what people tell them to do.

CAN I DRIVE A CAR USING A BMI?

Scientists build BMIs to make people's lives better. BMIs have applications ranging from health care to entertainment. BMIs can control wheelchairs, grab objects, and even communicate with other people [2]. Researchers are working on combining computer games with BMIs, so that people can control game actions with only their brains. Some researchers have created a virtual-ball-movement game that requires no physical interaction with the computer—the ball's movement is controlled only by the BMI [3]. This means we can have a brain controller instead of a joystick or keyboard. Researchers are also looking forward to a future in which our hands or feet will not be needed to drive. Nissan is working on a driving system that uses BMIs to steer a car. Much more work is necessary because driving is very complicated, and scientists want to make sure BMIs can drive as safely as possible.

WHAT ARE SOME CHALLENGES IN THIS FIELD?

BMIs are a new field and there are still many challenges. First, over time, the brain signal will slowly be lost because scar tissue will surround the electrode. Also, some BMIs run on batteries, and when the batteries die, doctors must replace them. This is inconvenient for patients—imagine if you had to have surgeries every several years!

Patients can also get infections during the surgeries. To solve this problem, scientists are building BMIs that have wireless charging [4]. Some mobile phones also have this new feature! Another big challenge is that we have different moods every day and even every moment, and it is difficult for the BMI to learn what we are thinking under all kinds of conditions. Another challenge is minimizing the attention that the user needs to spend on using the BMI. For example, you may be reading this article and drinking a cup of hot chocolate at the same time. You hold the cup easily and hardly think about it. However, this is challenging for a person with a robotic arm, who must focus hard to pick up the cup without spilling the drink. Luckily, when users become more familiar with their BMIs, they can pay less attention.

WHAT IF I WANT TO WORK IN THIS FIELD?

If you want to dive deeper into the world of BMI, you can start right now! There are many free resources dedicated to teaching children about the brain. Reading scientific journals, such as Frontiers for Young Minds, will help keep you up to date with new scientific discoveries in the field. BrainFacts.org is another great resource—a website dedicated to advancing brain research. This website has several fascinating articles about the brain, separated by grade level to maximize your understanding. Learning about programming and signal processing will also help you understand BMIs and what brain signals mean. When you get to high school, take classes like biology, anatomy, physiology, and computer science. These classes will introduce you to topics that will help prepare you for the BMI field.

In summary, BMIs are a very powerful and new technology. They can improve people's quality of life. Even though there are many challenges in this field, researchers try their best to make sure BMIs are safe for human use. This field is growing! If you are interested, you can use the suggestions above to join the field of BMI!

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CONFLICT OF INTEREST: The authors declare 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

VERDI ELEMENTARY SCHOOL, MS. MEIER'S CLASS, AGES: 10–11
Fifth Grade students at Verdi Elementary love Science. Verdi, Nevada is a little community squished up against the eastern side of the Sierra Nevada Mountains on the Truckee River. Verdi Elementary School is a cool place with lots of deer wandering on our streets and across the school yard. The deer is our school mascot. Learning about the brain and neuroscience was so interesting. We knew a little bit, because we are studying systems, ecosystems, and systems of the body this year.

VERDI ELEMENTARY SCHOOL, MS. NALL'S CLASS, AGES: 10–11
Verdi Fifth Graders love hands on science. Learning about the brain and neuroscience in conjunction with getting to see the actual brains was very exciting for the students. Verdi Elementary is in the small community of Verdi, Nevada which borders the California/Nevada state line. Our school mascot is the Mule Deer as we have a resident herd of deer frequent the area around our school, often slowing traffic down as they cross the road!

AUTHORS

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Hung-Yun Lu is a 4th-year Ph.D. student in the Santacruz Lab at the University of Texas at Austin. His current project is to study changes in a chemical called dopamine in the brains of monkeys, using a technique called fast-scan cyclic voltammetry. Hung-Yun is always fascinated by how the brain functions and even more surprised by how scientists can use information about brain functioning to improve the quality of people's lives. Outside of lab, Hung-Yun enjoys movies, music, reading, and playing with his lovely cat Sesame.

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