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# HOW CAN WE TRAIN THE BRAIN TO HELP STROKE PATIENTS?

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Many people who have had a stroke have trouble moving, even after therapy with the best experts and methods. New ways to make stroke therapy more effective could help people recover more effectively. Some research groups have developed brain-computer interface (BCI) systems that can measure when a stroke patient imagines hand movement by recording brain waves. We developed a BCI that used each patient's brain activity to control a muscle stimulator and a monitor during therapy. The patients got rewarding feedback during therapy when they imagined a movement correctly. We tested 51 patients, some of whom had a stroke many years ago. Forty nine patients improved after the therapy, based on the results of standardized tests. Therefore, BCI-based therapy could

help some stroke patients. We think there will be further advances in the next several years that will lead to more effective therapies using BCIs.

## WHAT HAPPENS WHEN A PERSON HAS A STROKE?

A stroke is a type of brain damage that is becoming more common because people are living longer. A stroke happens when a blood vessel in the brain is blocked or starts to bleed. In either case, some parts of the brain do not get the blood supply that they need, which can cause serious brain damage. After a stroke, it is important that the patient gets to a hospital immediately. Doctors can sometimes help patients recover from some of the brain damage within a few days after the stroke. However, even with hospital treatment, many patients have serious, long-lasting brain damage and need extensive therapy.

The brain consists of two halves, called the left and right **hemispheres**. Usually, a stroke only affects one hemisphere, so some stroke survivors have trouble moving the left or right side of the body. In severe cases, a patient's arm and leg on the left or right side may be completely paralyzed. In many milder cases, patients only have trouble with an arm or leg (not both) and can perform almost all movements normally. Stroke can cause another problem called **spasticity**. This means that some muscles are too tense. Patients might have pain, difficulty moving, unintended movements, and other problems.

Difficulty with movement can lead to many challenges. Stroke survivors might not be able to work or enjoy their favorite sports or hobbies. They might need help from friends and family, and they may have financial trouble from lost work and the costs of treatment and care. Some stroke survivors are uncomfortable being in public because they think people will tease them about their disabilities. These are only some reasons why we need the best possible approaches and technologies to help stroke patients recover the ability to move.

## HOW CAN BCI TECHNOLOGY BE USED TO TREAT STROKE PATIENTS?

Imagine a stroke patient who is no longer able to move one hand. To treat stroke patients, therapists often ask the patient to imagine or attempt certain kinds of hand movements. Over dozens of therapy sessions, this helps the brain relearn how to control the affected hand. A measurement called an **electroencephalogram (EEG)** has been used for many years to measure the brain's electrical activity [1]. This technique uses little metal discs called **electrodes**, which are placed on the head. The EEG can tell us which areas of the brain are active. For example, by placing electrodes over the brain areas responsible for

**HEMISPHERES**

The right and left halves of the brain. The left hemisphere controls movement on the right side of the body, and vice versa.

**SPASTICITY**

This disorder can include spasms (involuntary movements), stiff or tight muscles, pain, and overactive reflexes. People may have trouble with posture, walking, typical daily activities, and other movements.

**ELECTROENCEPHALOGRAM (EEG)**

A measurement of the natural electrical activity produced by the brain, obtained using electrodes placed on the head.

**ELECTRODES**

Small sensors that detect brain activity. EEG electrodes are generally small, metal disks mounted in a cap, which do not penetrate the skin nor cause pain.

movement and sensation, we can study the brain activity that happens when a person moves or feels a sensation.

**BRAIN-COMPUTER INTERFACE (BCI)**

System that uses direct measurements of brain activity to provide communication and control in real-time. Most BCIs use EEG to measure brain activity.

**MOTOR FUNCTION**

The ability to move parts of the body.

**BRAIN PLASTICITY**

The brain's remarkable ability to change itself to adapt to new information and situations, such as therapy. This ability helps people recover from stroke and other injuries.

EEG can be combined with a **brain-computer interface (BCI)** to create a new kind of stroke therapy. A BCI is a system that can provide real-time feedback about the brain's activity to the person receiving therapy. The BCI system can detect when patients imagine the correct hand movements and can let the patients know whether those movements are correct. For example, if the patient imagines a left-hand movement, then a cartoon hand on the monitor might mimic that movement, while a muscle stimulator helps the left hand to move. This way, the patient only gets rewarding feedback from the system while performing the imagined movement correctly. Seeing a cartoon hand move while also feeling their own hands move can help motivate patients and encourage their brains to relearn **motor functions**.

Many other types of BCIs have been developed [2–5]. Using BCIs in post-stroke therapy can lead to increased **brain plasticity**, meaning that the brain can create new connections that help it learn to perform certain functions again, such as moving the hand without spasms or other difficulties.

## TESTING BCI IN STROKE PATIENTS

We asked 51 patients to participate in our study. These patients were 61 years old, on average, and had their strokes an average of 37 months prior to the study. Some people believe that patients who had strokes more than 12 months ago will probably not improve, but we hypothesized otherwise.

The patients participated in two pre-assessments before the therapy. In the pre-assessments, we conducted tests to study each patient's motor skills and other factors. Pre-assessments were done on 2 different days, separated by 1 month, to ensure we had a good understanding of the abilities of the patients before the therapy. Then, the patients participated in 25 to 31 BCI therapy sessions with a licensed therapist. Each session lasted about 1 h, and most patients did 2 sessions per week (Figure 1). Afterwards, we did three post-assessments to study how each patient changed. The first post-assessment was done immediately after the last therapy session, and other post-assessments were done 1 and 6 months later.

## WHAT DID WE MEASURE?

We explored the effect of BCI therapy by measuring three separate factors: BCI accuracy; brain activity; and movement.

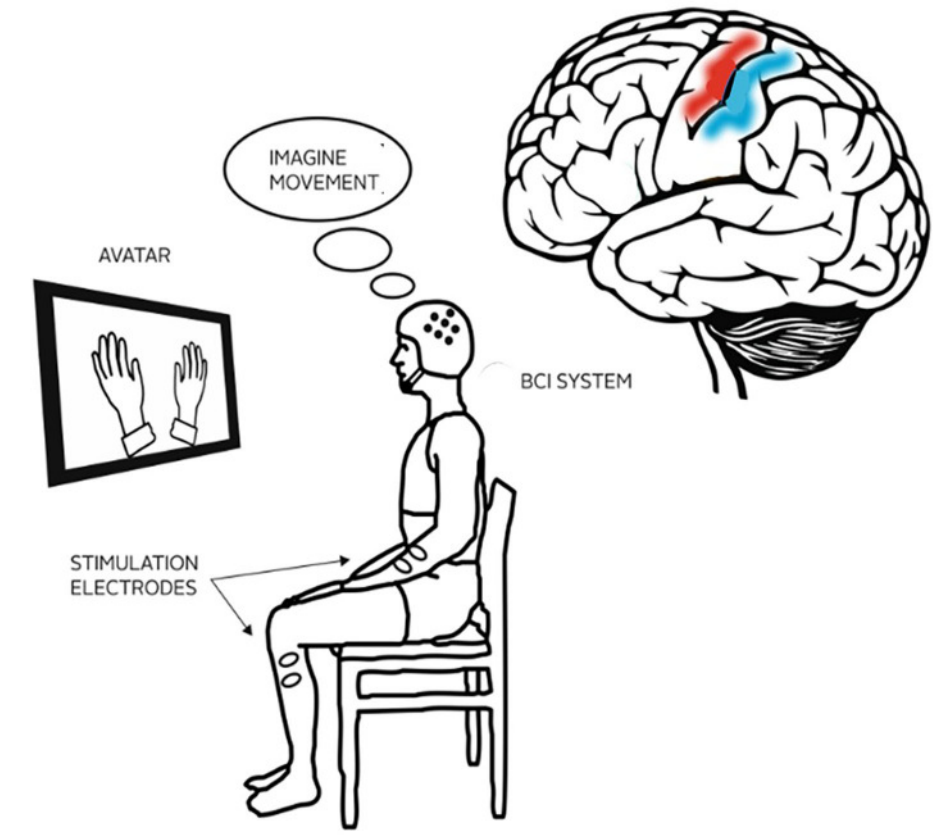



Figure 1

**Figure 1**

In BCI therapy, stroke patients wear an electrode cap and view a monitor where an image, such as moving hands, helps them relearn how to move. The BCI reads electrical signals from the brain, including those involved with movement and the feeling of touch (colored areas), and gives the patient feedback on the monitor when the movements are performed correctly. There are also stimulation electrodes attached to the patient that help him or her to perform each movement BCI therapy leads to improved motor functions because the neurons find new connections, through a process called brain plasticity.

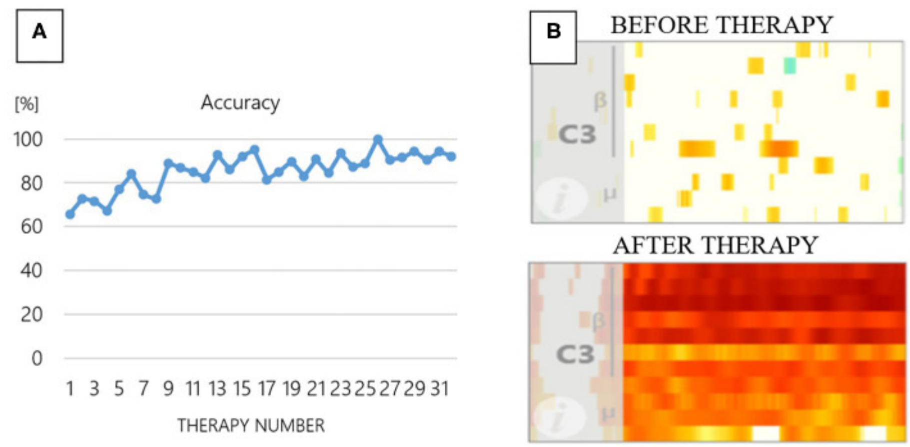
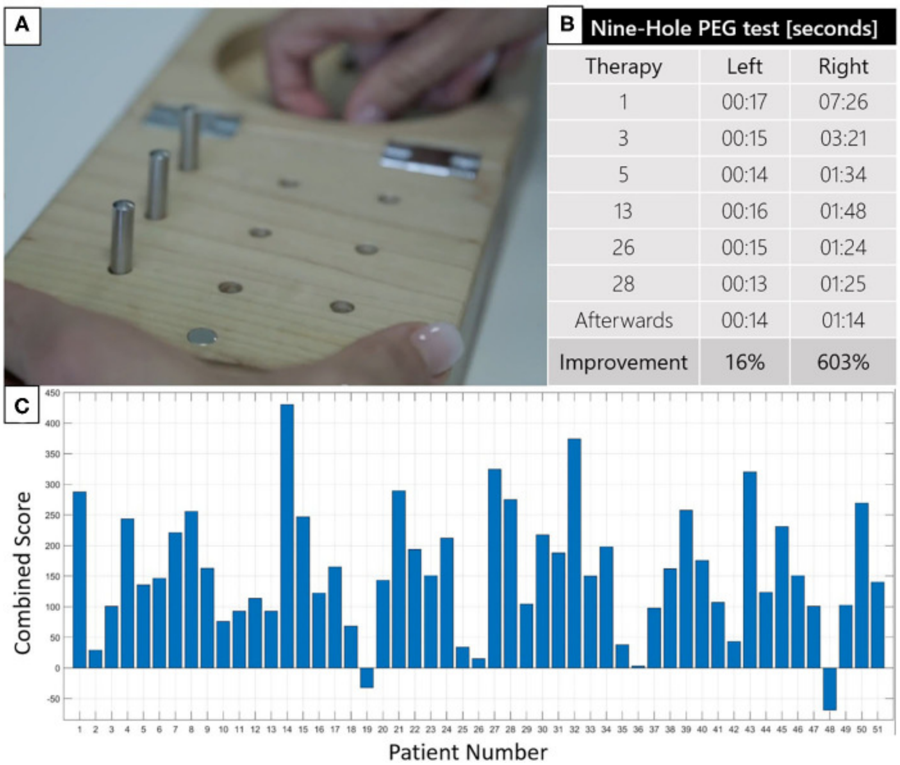



Figure 2

**Figure 2**

**(A)** BCI accuracy from therapy sessions 1 through 31 for one patient. At first, the BCI accuracy when classifying left- vs. right-hand movement was 65%. The accuracy improved with additional therapy sessions and reached 100% in session 25. **(B)** Brain activation before and after 31 sessions of BCI therapy. The white color before therapy indicates that there is no brain activation to produce hand and finger movements, while the red color after therapy indicates more brain activation. C3 is the name of the electrode position over the brain area responsible for right-hand movement.

*BCI accuracy* is a way to measure each patient's engagement in the motor imagery tasks. High BCI accuracy indicates that the patient is paying attention to the tasks and imagining the movements correctly. If the patient does not imagine any movement, then BCI accuracy will be around 50%. Therefore, low accuracy might indicate that the patient is not participating or is not imagining movements correctly. A therapist might then coach the patient to help him or her improve BCI accuracy (Figure 2A).




| Nine-Hole PEG test [seconds] | | |
|---|---|---|
| Therapy | Left | Right |
| 1 | 00:17 | 07:26 |
| 3 | 00:15 | 03:21 |
| 5 | 00:14 | 01:34 |
| 13 | 00:16 | 01:48 |
| 26 | 00:15 | 01:24 |
| 28 | 00:13 | 01:25 |
| Afterwards | 00:14 | 01:14 |
| Improvement | 16% | 603% |

Figure 3

**Figure 3**

**(A)** The Nine-Hole Peg Test can be used to test wrist and hand movement. **(B)** Results showing improvement of one patient's hand movement during BCI therapy. The time to complete the task with the affected (right) hand decreased from 7 min 26 s at the start of therapy to 1 min 14 s after 28 therapies. **(C)** Summary of all motor function tests, combined, for all patients studied. If the bar is above zero, movement was improved after the therapy. Forty nine patients showed improvements, while only two patients showed decreased movement (one had another stroke and the other did not pay attention).

*Brain activity* is measured throughout BCI therapy. Usually, in the early therapy sessions, the movement areas of the brain are not working together effectively. Over the weeks of therapy, we often see that the movement areas in the brain become much more active (Figure 2B). The colors in Figure 2B indicate the brain activation at different frequencies over areas that are important for movement. The x-axis indicates the time in each trial; areas further to the right indicate later times in the trial. The y-axis reflects different frequencies. The lower areas of the graph are lower frequencies (indicated by the Greek letter mu) and the higher areas of the graph are higher frequencies (indicated by the Greek letter beta).

The most important effect of BCI therapy is helping patients regain *movement*. Figure 3A shows a tool that therapists and scientists use to test wrist and hand movement, called the Nine-Hole Peg Test because the patient must pick up nine little pegs and put them into nine little holes. We asked patients to perform this test with both hands several times throughout the therapy process and we tracked the time it took them to complete the test. If BCI therapy helped a patient to regain movement, we saw a decrease in the time it took that patient to complete this test over the course of the therapy sessions (Figure 3B).

## WHAT DID WE LEARN FROM OUR STUDY?

We used many tests in addition to the Nine-Hole Peg Test to measure pain, spasticity, concentration, memory, and how well patients could perform different movements with and without help. Some tests were just questionnaires that asked about daily activities, such as whether the patient could put on a T-shirt without help. We conducted 18 tests with every patient, and a higher combined test score indicated a greater improvement in these tests (Figure 3C). Our results showed that the BCI therapy helped most patients regain movement and/or reduce spasticity in their hands and arms. We found that the therapy works better for patients who achieve more than 80% accuracy. BCI therapy even worked many years after the patient's stroke. One patient participated 31 years after the stroke and still improved! Our results told us that BCI therapy helped the patients' brains to learn how to better control their movements.

So far, our work has focused on rehabilitation for the arms and hands. In the future, we will use BCI therapy on stroke patients with affected legs, to improve their walking speed. Stroke can strongly impact people in many ways, and thus there is a strong need to explore new ways to help them recover. With additional research and development from our group and other groups, we hope to develop better therapy methods and devices so that patients can once again perform movements for work, fun, social events, and daily life activities.

## ORIGINAL SOURCE ARTICLE

Sebastián-Romagosa, M., Cho, W., Ortner, R., Murovec, N., Von Oertzen, T., Kamada, K., et al. 2020. Brain computer interface treatment for motor rehabilitation of upper extremity of stroke patients—a feasibility study. *Front. Neurosci*. 14:591435. doi: 10.3389/fnins.2020.591435

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**CONFLICT OF INTEREST:** The system used for the therapy is called recoveriX and is produced by a company called g.tec in Austria. CG is the CEO of g.tec. MS-R, WC, and RO are employees of g.tec.

The remaining 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

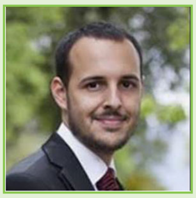
**RIDDHISH, AGE: 13**
I am a 8th grader. I enjoy reading about science, geography, history, and political sciences. I am passionate about bringing solution to problems related to human health.

**SPANDANA, AGE: 13**
Hello, my name is Spandana! I like to read sci-fi and play volleyball. I find science interesting and love to learn about psychology and space. Some of my hobbies are drawing, listening to music, and playing my guitar.

## AUTHORS

**CHRISTOPH GUGER**
Christoph Guger is from a small town in the mountains of Austria, a couple hours south of Germany. He loves hiking, skiing, and other mountain sports. He earned his Ph.D. in biomedical engineering in 1999, at a top Austrian technical university called the Technical University of Graz (TUG). He started a company called g.tec

medical engineering GmbH and has been the CEO there ever since. He studies and develops BCIs for patients with stroke, coma, epilepsy, and tumors. He also runs several research projects with people from different countries, which helped us do the research in this paper. *guger@gtec.at



**MARC SEBASTIÁN-ROMAGOSA**

Marc Sebastián-Romagosa is from Barcelona. He is a musician and loves hiking and mountain biking. Dr. Sebastián-Romagosa runs the recoveriX-gym, and he and his team use BCI technology to treat stroke patients. He is a trained physiotherapist who has experience working with stroke patients who want to learn to move again. Dr. Sebastián-Romagosa is also responsible for planning and executing scientific research projects. He uses different tests to measure the patients' motor functions, to help them become healthier and to learn more about how the brain heals. In 2018 and 2019, he was selected as the second-place winner as physiotherapist of the year in Catalonia, ranking just below the physiotherapist of FC Barcelona.

**WOOSANG CHO**

Woosang Cho is from Korea and did a lot of research in Germany. He joined g.tec's research department in 2016, where he works on BCIs to help people recover movement. He studies how feedback and brain stimulation can help people learn to move again. People with stroke, injuries, or other conditions may have healthy bodies, but their brains can no longer control movement correctly. Woosang hopes to help people use BCIs and other technologies as part of future therapies that could help people walk, grasp, or speak again.

**TIM VON OERTZEN**

Tim von Oertzen is the head of the Department of Neurology 1 at the Kepler Universitätsklinikum in Linz, Austria. This is a top hospital for treating stroke patients, and Linz is a famous European city on the beautiful Danube River. Like Dr. Kyousuke Kamada, Dr. Oertzen is a medical doctor who has additional medical training to help patients recover from brain injuries. Tim has very extensive knowledge about strokes and how to treat them successfully. He and his wife run a Recoverix-gym to treat stroke patients in Linz. He also is a very successful hunter.

**KYOUSUKE KAMADA**

Dr. Kyousuke Kamada received his Ph.D. in medicine in 1995. His professional career includes research at Hokkaido University, Japan, University of Erlangen-Nürnberg, Germany, Georgetown University, USA, and University of Tokyo, Japan. He was professor and chairman of the Department of Neurosurgery at Asahikawa Medical University, Japan. Today, he helps patients and conducts research at the Mengumino Hospital in Sapporo, Japan. Dr. Kamada is an expert in neuroscience and biomedical engineering. His present research topics include functional brain mapping for brain surgery, BCIs, assessment of brain functions, and brain rehabilitation.

**BRENDAN Z. ALLISON**

Brendan Allison earned his Ph.D. in cognitive science at U.C. San Diego. He then worked for Prof. John Polich in California, Prof. Jonathan Wolpaw in New York, and Prof. Gert Pfurtscheller at TUG in Austria. Most of Brendan's work involves using BCIs to provide communication for people who cannot move. In the last several years, he has also worked on BCIs for other types of patients, including people with stroke.

Brendan also does volunteer work to help the BCI community in several ways, such as working with the BCI Society, giving numerous lectures, and writing.

**RUPERT ORTNER**

Rupert Ortner is one of the top programmers at g.tec and has worked with EEG-based BCIs for many years. He leads several programming and development projects, including work with patients who had a stroke or were diagnosed with a disorder of consciousness. Dr. Ortner earned his Ph.D. at Kepler University in Austria. During his Ph.D. work, he developed non-invasive BCIs for disabled people. For example, he developed an SSVEP BCI to control an orthosis, which is a device that helps disabled people move their arms. Dr. Ortner also enjoys skiing and travel.