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# "PLASTIC" CONNECTIONS BETWEEN NEURONS HELP US LEARN AND REMEMBER

***Chiara Di Fazio[1,2*], Elena Protopapa[3] and Sara Palermo[1,4,5]***

*[1] Department of Psychology, University of Turin, Turin, Italy*
*[2] International School of Advanced Studies, University of Camerino, Camerino, Italy*
*[3] Studio di Neuropsicologia Ponti srl, Ravenna, Italy*
*[4] Neuroradiology Unit, Diagnostic and Technology Department, Fondazione Istituto di Ricovero e Cura a Carattere Scientifico (IRCCS) Istituto Neurologico Carlo Besta, Milan, Italy*
*[5] Neuroscience Institute of Turin (NIT), Turin, Italy*

YOUNG REVIEWERS:

VEENA
AGE: 15

YALE PATHWAYS
AGES: 11–14

Learning and memory happen because of a special brain process called Hebbian plasticity. This process makes the connections between brain cells, called neurons, stronger when the neurons work together. These stronger connections help us think, learn new skills, and remember things. Scientists are studying how Hebbian plasticity works and using tools like transcranial magnetic stimulation (TMS) to change these brain cell connections without the need for surgery. By understanding Hebbian plasticity, researchers hope to find better ways to help people learn, improve memory, and even treat brain-related problems like depression or memory loss.

## HOW DO WE LEARN AND REMEMBER?

The brain is an incredible organ that controls everything we do, from thinking and dreaming to moving and feeling. But have you ever thought about *how* your brain learns and remembers things? Well, this is where a concept called **Hebbian plasticity** comes into play.

Hebbian plasticity is a scientific concept that explains how the brain's communication cells, called **neurons**, form connections with each other. The connections between neurons are called **synapses**, and synapses allow signals to be sent from one neuron to another. Synapses can become stronger or weaker depending on how often they are used—synapses become stronger when they are used repeatedly [1]. This ability to change the strength of connections between cells helps the brain adapt to new experiences.

When we are born, our brains have many more connections between neurons than we actually need—like a dense forest full of vines and tangled paths. As we grow and learn from our experiences, some of these connections become stronger and more important, while others become weaker. For example, when you start learning to play an instrument, your brain strengthens the connections that help you play better, while the less useful connections become weaker. This process is like walking through a forest for the first time: at first, the path is unclear, and vines may block your way. But each time you walk the path, it becomes clearer and faster to follow, as you find shortcuts and clear the obstacles out of the way. Similarly, Hebbian plasticity helps us learn and grow by making the important connections in our brains stronger and more efficient.

Hebbian plasticity occurs when neurons "fire" together. This means that when neurons are active at the same time, their connection becomes stronger. Think of it like a sports team—when players work together and practice the same movements, they become more coordinated and effective. Similarly, when neurons repeatedly fire together, their connection is strengthened, making it easier for them to work together in the future. This process can take place with just two neurons, but often many neurons fire simultaneously, like a whole team working in sync. The more neurons fire together, the stronger their connections become, creating a more efficient network in the brain. This process is important for learning and memory [2]. Just as practicing a sport helps to improve your skills, Hebbian plasticity strengthens the connections in your brain and helps you learn faster and more effectively.

## HOW HEBBIAN PLASTICITY HELPS YOU LEARN AND REMEMBER

Imagine learning to ride a bike. At first it is challenging, but as you practice, your brain strengthens the connections related to balancing,

**HEBBIAN PLASTICITY**

A type of synaptic plasticity where simultaneous activation of neurons strengthens the synapse, encapsulated by the phrase "cells the fire together, wire together".

**NEURONS**

Cells of the nervous system responsible for transmitting electrical impulses and processing information within the brain and throughout the body.

**SYNAPSES**

Specialized junctions between neurons that enable transmission of electrical or chemical signals, facilitating communication within the nervous system.

pedaling, and steering. This is Hebbian plasticity at work [3]. The more you practice, the stronger these connections become, making it easier for you to ride the bike without falling. It is like your brain is saying, "This is important! I will make these connections stronger so you can do it better next time!". Hebbian plasticity is also important for learning sports and musical instruments. For example, if you develop a consistent learning routine, like by practicing regularly, the brain strengthens the neural pathways that help you to store and remember what you are trying to learn. Similarly, in sport, repetitive practice of a particular movement, such as a tennis serve or a basketball dribble, creates stronger connections in the brain and improves your skill with those movements over time. In learning musical instruments, frequent practice of scales or techniques strengthens neural pathways, making it easier to learn more complex compositions.

## HEBBIAN PLASTICITY AND MENTAL HEALTH

Did you know that the way your brain learns and remembers can also affect how you feel? Hebbian plasticity is not just about learning new skills like riding a bike—it also helps your brain stay healthy. In some conditions, such as depression or post-traumatic stress disorder (PTSD), the problematic symptoms can be caused by the poor function of certain brain connections [4]. Imagine if the pathways between important parts of your brain were weak or broken. When brain pathways are weak, it can be harder to think clearly, concentrate, or feel happy. When a person experiences stress or trauma, Hebbian plasticity can also accidentally strengthen harmful connections. This happens because the brain is trying to protect itself, but sometimes it ends up strengthening neural pathways that make a person more vulnerable to negative emotions or stress responses. Fortunately, learning how to strengthen "positive" neural pathways, such as those involved in healthy coping strategies, physical activity, or resilience, can help restore balance, improving people's moods and overall mental wellbeing.

## CHANGING HEBBIAN PLASTICITY FROM OUTSIDE THE SKULL

**NON-INVASIVE BRAIN STIMULATION (NIBS)**

Techniques that modulate neural activity through external means, such as magnetic fields or electrical currents, without the need for surgery.

**Non-invasive brain stimulation (NIBS)** techniques are methods used to alter brain activity without the need for surgery. The term "non-invasive" means that these techniques are safe and painless, applied externally to the skull, and can influence the brain's function by modulating the activity of neurons. The term "non-invasive" means that these methods influence brain function from the outside of the skull, without requiring surgery. NIBS can help scientists and doctors safely explore how the brain works, so they can understand how people learn and remember things. There are several types of

NIBS, including **transcranial magnetic stimulation (TMS)**, which uses magnetic fields to stimulate specific brain areas, and **transcranial direct current stimulation (tDCS)**, which delivers a low electrical current to modulate brain activity.

NIBS can affect Hebbian plasticity in the brain: when a specific part of the brain is stimulated using NIBS, it can change the strength of the connections between neurons, just like practicing a skill can strengthen those connections [5]. This change in neuron activity can improve learning processes by strengthening synapses, particularly in brain areas involved in memory and **cognition**. For example, TMS can be targeted at brain regions responsible for **working memory**, improving the brain's ability to encode, store, and retrieve information. Additionally, NIBS techniques are being investigated for therapeutic purposes, such as treating neurological conditions like depression and memory disorders. By modulating Hebbian plasticity, NIBS helps researchers understand brain adaptability and hold potential for improving cognition and addressing neurodegenerative disorders like Alzheimer's disease.

**TRANSCRANIAL MAGNETIC STIMULATION (TMS)**

A non-invasive neuromodulation technique that uses magnetic fields to induce electrical currents in specific cortical regions, altering neuronal excitability and activity.

**TRANSCRANIAL DIRECT CURRENT STIMULATION (TDCS)**

A non-invasive technique that applies a low electrical current to the scalp to modulate cortical excitability, often used to enhance cognitive and motor functions.

**COGNITION**

Set of mental processes involved in the acquisition, manipulation, and application of knowledge, including perception, attention, memory, language, and decision-making.

**WORKING MEMORY**

A cognitive system responsible for the temporary storage and active manipulation of information needed for complex tasks such as comprehension, learning and problem-solving.

## HOW DOES NIBS WORK?

Imagine your brain as an orchestra, in which every neuron is a musician playing its part. The connections between the neurons are like the symphony created when the musicians play together. Now imagine the TMS coil as the conductor of this orchestra, sending magnetic pulses to specific parts of the brain to help the neurons "play" in sync and increase activity in regions that are important for mood and learning. TMS helps the brain work harmoniously by strengthening connections and increasing activity where it is needed most. In conditions such as depression, where certain regions of the brain are underactive, TMS stimulates these regions, "waking up" the underperforming networks of neurons. TMS stimulation enhances Hebbian plasticity by helping neurons to fire in sync with each other, which, as you now know, strengthens their connections. For example, stimulating the part of the brain involved in mood regulation can help reduce symptoms of depression by "rewiring" brain areas that are not working properly.

TMS can be used to help understand and even improve the brain's ability to learn and remember. Some studies suggest that, by changing Hebbian plasticity, NIBS may even influence the brain's ability to be aware of and understand the world around us (Figure 1) [5].

## THE POWER OF HEBBIAN PLASTICITY

In conclusion, Hebbian plasticity is a fascinating process that helps us learn, remember, and become aware of the world around us.

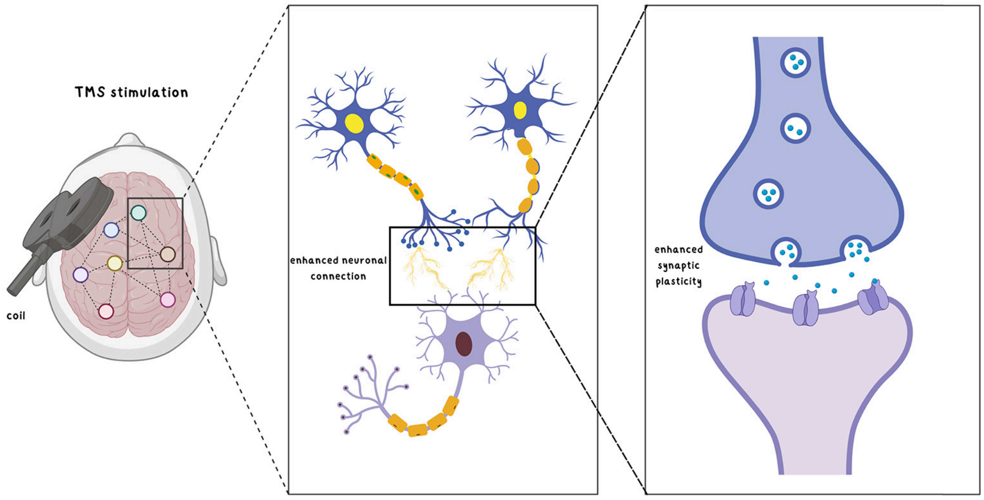


Figure 1

**Figure 1**

Changing Hebbian plasticity through NIBS. NIBS techniques such as TMS can stimulate Hebbian plasticity by changing the activity of neurons and strengthening synapses. This figure shows how TMS can stimulate specific brain areas, causing neurons on both sides of synapses to fire together and thereby "wiring" them together. TMS uses a magnetic field to stimulate the brain, which generates harmless electrical currents in the neurons. This electric field can change the activity of neurons in the stimulated area, potentially strengthening synaptic connections.

Changing connections within the brain using non-invasive techniques such as TMS could help to treat mental health problems such as depression and PTSD. So, the next time you learn something new or remember an old memory, remember that Hebbian plasticity made it all possible. Continue to be curious about the incredible world inside your head!

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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

### VEENA, AGE: 15

Hai! My name is Veena, I am 15 and I am in my freshman year of highschool. I am a gymnast and a cheerleader, and I like going to the beach in my free time. I enjoy working with and helping out in my school's special education department. I am interested in and would like to work in the field of psychiatry.

### YALE PATHWAYS, AGES: 11–14

Yale Pathways students love chocolate lava cake, pizza, mac and cheese, and vanilla ice cream. The students play various sports like figure skating, soccer, basketball, and swimming, as well as instruments such as piano, violin, and guitar!

## AUTHORS

### CHIARA DI FAZIO

Chiara Di Fazio is a Ph.D. student specializing in brain research. She uses Non-invasive brain techniques, such as Transcranial Magnetic Stimulation (TMS), to explore how brain activity affects perception, memory and cognitive function. Chiara focuses on using neuromodulation techniques to improve brain health, particularly in healthy older adults and patients with cognitive and emotional disorders. Her research aims to develop new ways to support brain function, enhance learning, and improve mental wellbeing through non-invasive methods. *chiara.difazio@unito.it

### ELENA PROTOPAPA

Elena Protopapa is a psychologist with a degree in Neuroscience and Neuropsychological Rehabilitation from the University of Bologna, currently undergoing further training in Cognitive-Behavioral Psychotherapy at the Miller Institute in Florence. Her areas of expertise include anxiety disorders, mood disorders, emotional education, hyperactivity and inattention, stress management, personal growth, and awareness programs. She also provides support to parents and helps with trauma processing. With a creative and tailored approach, Elena helps individuals transform each step of their journey into an educational and self-discovery experience.

**SARA PALERMO**

Sara Palermo holds an MSc in Clinical Psychology and a PhD in Experimental Neuroscience. She is an Associate Professor of Neuropsychology and Cognitive Neuroscience at the University of Turin. Additionally, she collaborates as a Scientific Consultant with the Neuroradiology Department of the IRCCS Istituto Neurologico Carlo Besta in Milan. She also serves as the Scientific Director of the National Institute of Philanthropy and is the Assistant Specialty Chief Editor for *Frontiers in Psychology - Neuropsychology*. Her research focuses on Brain Aging and frailty in the elderly, metacognitive and executive functions in neuropsychiatric and neurological disorders, and placebo/nocebo phenomena. Dr. Palermo is an ordinary member of several prestigious organizations, including the American Psychological Association (Divisions of Neuropsychology and Military Psychology), the Italian Society of Neuropsychology, the Italian Association of Psychogeriatrics, the Italian Society of Neurology for Dementia, and the International Society for Interdisciplinary Placebo Studies. Recently, she was appointed as a Corresponding Member of the European Academy of Neurology.