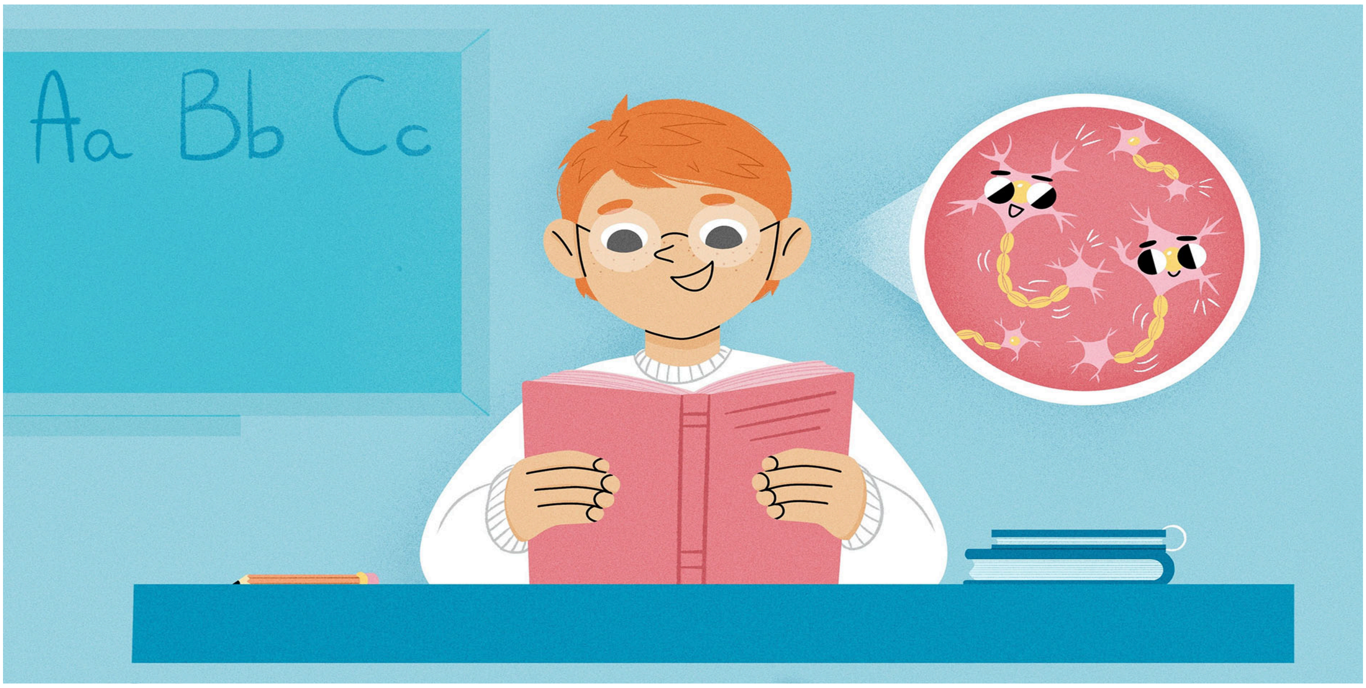
NEUROSCIENCE AND PSYCHOLOGY
Published: 11 January 2024
doi: 10.3389/frym.2023.979294



THE PLAY-DOH BRAIN: HOW SHAPEABLE NEURONS HELP YOU LEARN AND REMEMBER

Elisa Corti[1*†], Manuela Rizzi[2*†], Carlos B. Duarte[1] and Emily K. Osterweil[2]

[1]Center for Neuroscience and Cell biology, University of Coimbra, Coimbra, Portugal

[2]Centre for Discovery Brain Sciences, University of Edinburgh, Edinburgh, United Kingdom

[†]These authors have contributed equally to this work

YOUNG REVIEWERS:


ARITRO
AGE: 14


JORDAN
AGE: 9

Imagine that your mom just baked a pizza, and you immediately take a bite of it. Bad choice—it is really hot, and you burn your tongue! You learn a lesson from this experience, but what is happening in your brain? When the burning sensation reaches the brain, some brain cells, called neurons, become active and communicate with each other. Thanks to a process called synaptic plasticity, neurons can increase the strength of their communication and store new information. The next time your mom prepares pizza, the same neurons that were active the first time will start talking again, and you will know to wait for it to cool down before taking a bite. In this article, we will describe some properties of neurons and what happens to these cells when you create new memories. We hope that you will learn something new and share it with your friends, as neurons would do!

THE BRAIN: CONTROL CENTER OF THE BODY

The brain is probably the most complex and mysterious structure within a living thing. The human brain contains about 86 billion cells called neurons and even more support cells—an impressive number of cells! The brain controls most of the activities of the body: moving, seeing, thinking, dreaming, storing memories, and so on.

One of the most incredible abilities of the brain is learning. Do you know how many things you have learned in your life? When you were a baby you learned many things for the first time, for example the words "mom" or "dad," the colors, and names of animals. Then, you started going to school and studying hundreds of different facts (What is the capital of Italy? When was America discovered? How much is 7 × 5?). Maybe you are learning how to play an instrument, or how to cook brownies. Your brain stores and retrieves all this information when you need it in your everyday life. But what is really happening inside the brain that makes us learn and recall memories?

TALKATIVE NEURONS

To understand learning, we need to take a step back and talk about neurons and their structure. There are many kinds of neurons but they all have certain parts in common (Figure 1). For example, all neurons have a main part, called the cell body. Neurons also have **dendrites**, which are short, tree-like "branches." The ends of the dendrite branches have small protrusions called **post-synaptic terminals**. These are the "ears" of a neuron—they allow the neurons to receive messages. Each neuron also has one **axon**, which is a long, tube-like fiber that can be up to 2 meters long (about 6 feet). At the end of the axon, there are tiny structures called **pre-synaptic terminals**. These are like the "mouth" of a neuron—they communicate messages to other neurons nearby.

As we mentioned, neurons "talk" to each other. The neuron that "talks" is called the pre-synaptic neuron, the neuron that "listens" is called post-synaptic neuron, and the zone of communication is called the **synapse**. When the talking neuron wants to say something to its neighbor, it sends a signal along the axon. When the signal arrives at the end of the axon, a chemical message is sent to the post-synaptic terminals of the listening neuron. At this point there are two possibilities: if the message is not strong enough, the listening neuron will not communicate this information to another neuron, remaining silent. If the message is strong, the listening neuron will in turn become a talking neuron, and the message will travel from the dendrites, through the cell body, to the pre-synaptic terminal where it will be communicated to another neuron. Does this remind you of the "broken telephone" game?

DENDRITE

Short, branching fiber extending from the cell body of the neuron, with the function of receiving signals from other neurons.

POST-SYNAPTIC TERMINAL

Tiny structure at the end of the dendrite, that represents the receptive site of the neuron. Here, messages in the form of chemical signals are received from another neuron.

AXON

Long cable that originates from the cell body of the neuron. Messages from the neuron travel along this cable to be received by other neurons.

PRE-SYNAPTIC TERMINAL

Tiny structure at the end of the axon, that represents the communicative site of the neuron. Here, messages in the form of chemical signals are sent to another neuron.

SYNAPSE

Structure delimited by a pre-synaptic and a post-synaptic terminal where communication between neurons happens: here the signal sent by the pre-synaptic neuron is transmitted to the post-synaptic neuron.

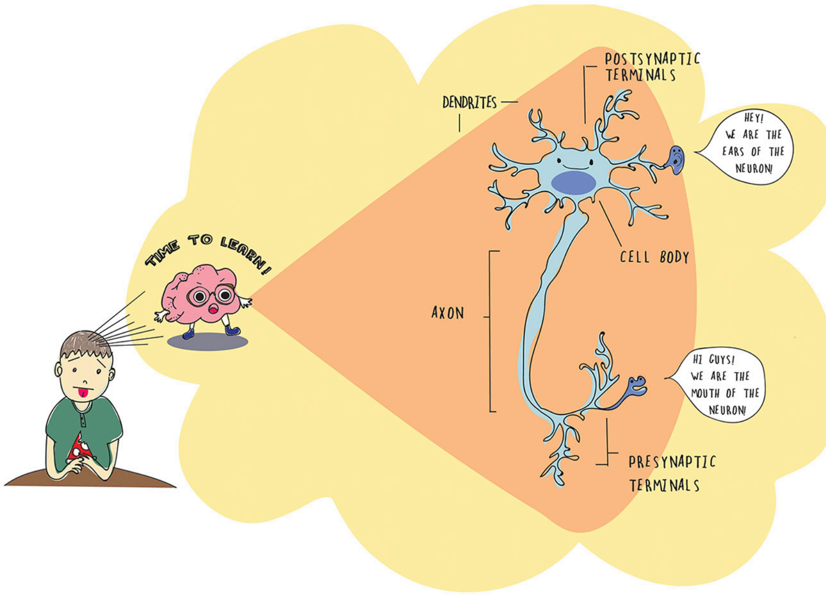


Figure 1

Figure 1

Brain cells called neurons allow us to learn. You can see the cell body, the axon with its pre-synaptic terminals, and the dendrites with their post-synaptic terminals. The post-synaptic terminals are like the "ears" of the neuron. They "listen" for messages from other neurons. When the message is strong enough, it travels through the cell body and down through the axon. The pre-synaptic terminals are like the "mouth" of the neuron, and they then relay the message to other nearby neurons.

PRACTICE MAKES PERFECT

Imagine you want to learn how to play the guitar: you need to make the same hand motions over and over. Over weeks, as you continue playing, your hand movements will become more fluid, and you will be able to play faster. In the early stages of learning, however, if you quit playing for a while and then pick up the guitar again sometime later, playing will probably be as difficult as it was when you first started. What is going on with the brain's neurons during this process?

Neurons have a remarkable property called **synaptic plasticity**, which gives them the ability to adapt the numbers and sizes of their pre-synaptic and post-synaptic terminals according to changes in their communication with other neurons (Figure 2). When you practice playing the guitar, some neurons talk more as you learn the music, control your movements, and coordinate your left and right hands. This means that the pre-synaptic neurons involved in controlling these actions send more signals to the post-synaptic neurons (becoming better speakers), and the post-synaptic neurons may enlarge or increase their number of post-synaptic terminals (becoming better listeners), or both. New synapses form, neurons communicate more easily, and it becomes easier for these neurons to talk in the future. If you stop training, this group of neurons stops talking. The pre-synaptic neurons send weaker signals and the post-synaptic neurons decrease the size and number of post-synaptic terminals.

SYNAPTIC PLASTICITY

Process by which neurons reshape to adapt to the signals reaching the brain, resulting in strengthening of the connections that store something learned as a memory.

In this way, you can think about the brain as a mound of play-doh, able to reshape itself depending on the information it receives and on the movements it has to control.

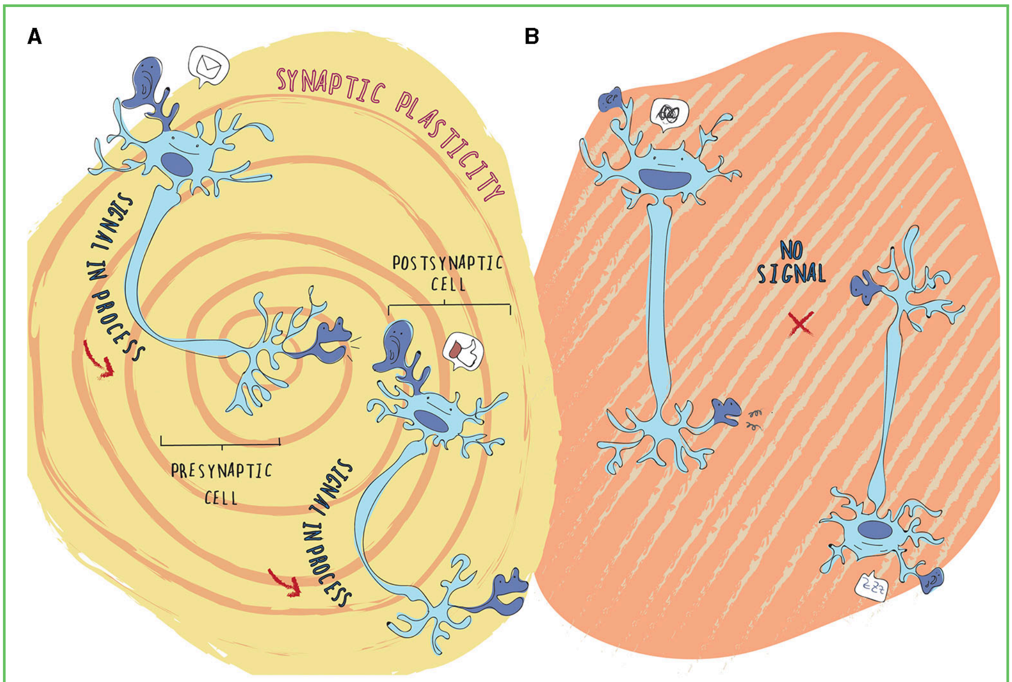


Figure 2

Figure 2

Synaptic plasticity. **(A)** Two neurons having an interesting talk: the pre-synaptic cell speaks loudly, and the post-synaptic cell listens carefully. This is what happens when you learn how to play the guitar. As you learn the music and coordinate your left and right hands, both the pre- and post-synaptic terminals get bigger, to make the communication between neurons easier. **(B)** Two neurons that are not talking to each other clearly enough: this is what happens when you do not practice enough. In this case, after some time the pre- and post-synaptic terminals become smaller, and neurons stop communicating.

FOCUS OR FORGET

When learning how to play the guitar, passion and focus are the main motivators that will keep you practicing and eager to become a great musician. In the same way, neurons need to be focused to keep talking.

In your brain, billions of neurons are all talking at the same time. It is a hot mess! When you practice playing the guitar frequently, you are making some neurons talk and listen better. But, to focus, you also need to silence the voices coming from neurons that are interested in watching TV or talking about what to eat. So, when you play the guitar, the focussed neurons increase the volume of their voices and talk more efficiently between themselves compared to the ones that are not interested, which decrease the volume of their voices, blocking distraction coming from other neurons.

Synaptic plasticity makes focussed neurons better speakers and listeners, but if the signals are not strong and repeated over time, the neurons soon "lose interest" and stop talking. Their pre-synaptic and post-synaptic terminals shrink back to the way they were before, and neurons may even forget about their conversation.

POTENTIATE THE FOCUSSED NEURONS: THE ROLE OF PROTEINS

If you play the guitar for years, eventually, even if you take a year off, you will still remember how to play if you pick up a guitar again. You might be a bit rusty, but with just a little practice you will be back to your former level—much more quickly than when you learned the first time. How does the brain do this?

After they talk to each other for long enough, neurons start to record and organize the relevant information collected through the communication, turning it into a memory. At this point, the synapses become stabilized, which means the focussed neurons, that were able to clearly communicate after years of practice, are strengthened and maintained active while neurons that do not speak clearly are excluded from this conversation. The process of stabilizing new synapses is called **long-term potentiation** (LTP). At the same time, it becomes easier to focus and ignore the background noise. The post-synaptic terminals whose job it was to listen to this background noise become smaller and stay that way. This process is called **long-term depression** (LTD). These processes are coordinated by proteins, that have the role to maintain the synapse stable. Most proteins are made in the cell body of neurons, where specialized protein-production factories called ribosomes are located (Figure 3). However, during memory formation, proteins are needed in the focussed synapses. Interestingly, scientists have taken photographs of dendrites, showing that they have protein factories there as well as in the cell body. This means that the specialized proteins that help us form memories are ready to be supplied when and where they are needed [1, 2].

LONG-TERM POTENTIATION

Form of synaptic plasticity in which neuronal communication is enhanced in the long term, resulting in permanent changes in neuronal structure. This happens when memories are formed.

LONG-TERM DEPRESSION

Form of synaptic plasticity in which neuronal communication is reduced in the long term, resulting in permanent changes in neuronal structure. This happens to neurons that do not communicate efficiently.

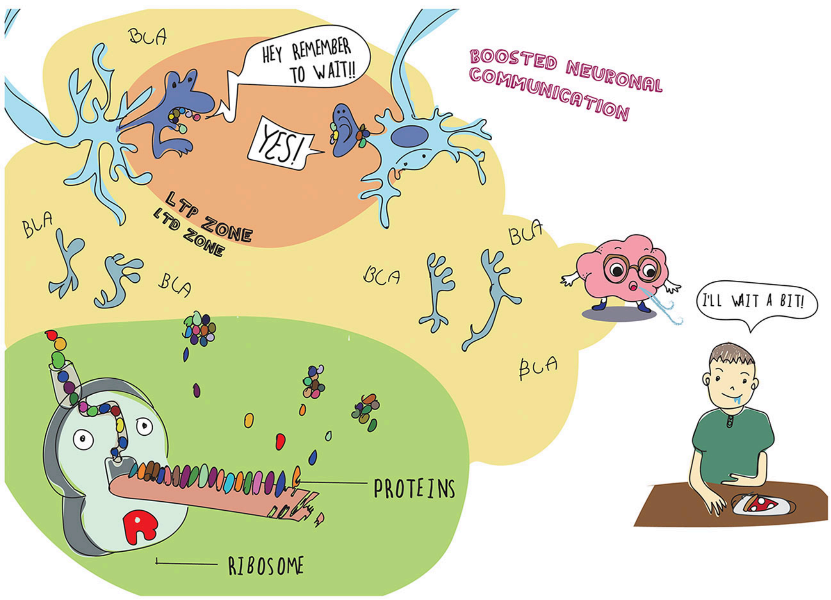


Figure 3

Figure 3

After you burn your tongue by eating a slice of pizza just baked by your mom, neurons in your brain start recording information in the form of a memory helped by proteins, which are produced in axons and dendrites, in factories called ribosomes. Proteins help strengthen focussed neurons in a process called LTP and silence background noise in a process called LTD. When this happens, new memories are formed in your brain. In this case, the next time your mom bakes the pizza you will know to wait for it to cool down before biting a slice.

SUMMARY

To wrap up, the new memories that you acquire, or the new skills that you learn, are created from the synapses that are formed and stabilized while you are learning. For example, after learning how to play a particular guitar chord, new synapses are formed in your brain. Every time you play that chord, these synapses will be active and will control the movement of your hands on the guitar. Although it is still not very well understood, it is clear that protein production in the brain is key for learning [3]. Some diseases share difficulties in learning, and scientists have figured out that this may result from bad functioning of the ribosomes in neurons [4]. Studying which proteins are produced in the brain and what triggers their production might help us to understand the basis of memory. This knowledge could eventually help us to treat diseases that cause learning or memory problems.

ACKNOWLEDGMENTS

Special thanks to Principal Investigators CBD and EKO for their feedbacks during the writing process and to Ota Luna Shawa for drawing the figures. Additional thanks to Marta Gonçalves from PIN (clinic for child development) for a special review with a 12 years old ADHD's boy. This work was funded by the grant MSCA-ITN Syn2Psy (ID:813986).

REFERENCES

1. Rangaraju, V., Tom Dieck, S., and Schuman, E. M. 2017. Local translation in neuronal compartments: how local is local? *EMBO Rep.* 18:693–711. doi: 10.15252/embr.201744045
2. Sutton, M. A., and Schuman, E. M. 2006. Dendritic protein synthesis, synaptic plasticity, and memory. *Cell* 127:49–58. doi: 10.1016/j.cell.2006.09.014
3. Schafe, G. E., and LeDoux, J. E. 2000. Memory consolidation of auditory pavlovian fear conditioning requires protein synthesis and protein kinase A in the amygdala. *J. Neurosci.* 20:RC96. doi: 10.1523/JNEUROSCI.20-18-j0003.2000
4. Kelleher, R. J., 3rd, and Bear, M. F. 2008. The autistic neuron: troubled translation? *Cell* 135:401–6. doi: 10.1016/j.cell.2008.10.017

SUBMITTED: 27 June 2022; **ACCEPTED:** 15 December 2023;
PUBLISHED ONLINE: 11 January 2024.

EDITOR: Anna Alkozei, University of Arizona, United States

SCIENCE MENTORS: Pat Levitt and Sucharita Saha

CITATION: Corti E, Rizzi M, Duarte CB and Osterweil EK (2024) The Play-Doh Brain: How Shapeable Neurons Help You Learn and Remember. Front. Young Minds 11:979294. doi: 10.3389/frym.2023.979294

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

ARITRO, AGE: 14

Hello! I'm an exuberant violist and enjoy playing with the local youth orchestra. Summer gives me the opportunity to play tennis with friends and go on long kayaking trips with my family. I love traveling and was able to travel to Austria to tour and play music with my orchestra in summer.

JORDAN, AGE: 9

I am in third grade. I enjoy different kinds of science. I like to explore things like different rocks, snails, worms, and I really like to look at different birds. I like to learn about animal habitats. Space is my favorite subject because there is a huge galaxy that no one has discovered. When I am older, I want to be a scientist that explores space. My favorite animal is a hamster because it is small and cute.

AUTHORS

ELISA CORTI

Elisa Corti is a Ph.D. student at the Center for Neuroscience and Cell Biology in Coimbra under the supervision of Prof Carlos Duarte, Prof Paulo Pinheiro and Prof Ramiro Almeida. She is part of the European-founded consortium Syn2Psy, where together with other 13 researchers working in different laboratories around Europe, she tries to understand how non-functional neuronal communication results in disease. More in detail she studies a specific protein called Fragile X messenger ribonucleoprotein that has an important role in neuron development and activity and when dysfunctional, causes a disease called Fragile X Syndrome. Before starting her Ph.D., she obtained a bachelor's in biology at the University of Milan, then she moved to Trieste to enroll in the International Master's Degree in Neuroscience. *elisacorti7@gmail.com

MANUELA RIZZI

Manuela Rizzi is a Ph.D. student working at the University of Edinburgh in Emily Osterweil's group, and she is part of the European consortium called Syn2Psy where together with other 13 researchers working in different laboratories around Europe, she tries to understand how non-functional neuronal communication results in disease. In her research project she tries to understand if similar

proteins disrupt learning and neuronal communication in two disorders called Fragile X Syndrome and SYNGAP1 haploinsufficiency. Her former education is in biology (bachelor's degree) at the University of Ferrara and molecular and cellular biotechnology-neuroscience (master's degree) at the University of Trento, followed by an experience of 6 months in the behavioral Neuroscience Lab in Lund (Sweden). *m.rizzi@sms.ed.ac.uk

CARLOS B. DUARTE

Carlos B. Duarte is a professor at the University of Coimbra and leader of Neuronal signaling group at the Center for Neuroscience and Cell Biology (University of Coimbra, Portugal). His work focuses on understanding the mechanisms of neuronal communication, as well as their alterations that originate in neurological disorders such as hypoxia, ischemia and epilepsy.

EMILY K. OSTERWEIL

Emily K. Osterweil is an associate professor of Neurology at Harvard Medical School in Boston and previously in the Center for Discovery Brain Sciences in Edinburgh. Her research follows the hypothesis that new protein synthesis in the brain is a fundamental requirement for learning, and dysregulation of this process contributes to disease, such as autism spectrum disorders. During her postdoctoral tenure in the laboratory of Prof. Mark Bear at the Massachusetts Institute of Technology, she discovered a novel treatment strategy for Fragile X Syndrome and received multiple awards.