

# Who are you?

**Edited by**

Axel Cleeremans, Changiz Mohiyeddini, Livio Provenzi  
and Sara Palermo



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## Who are you?

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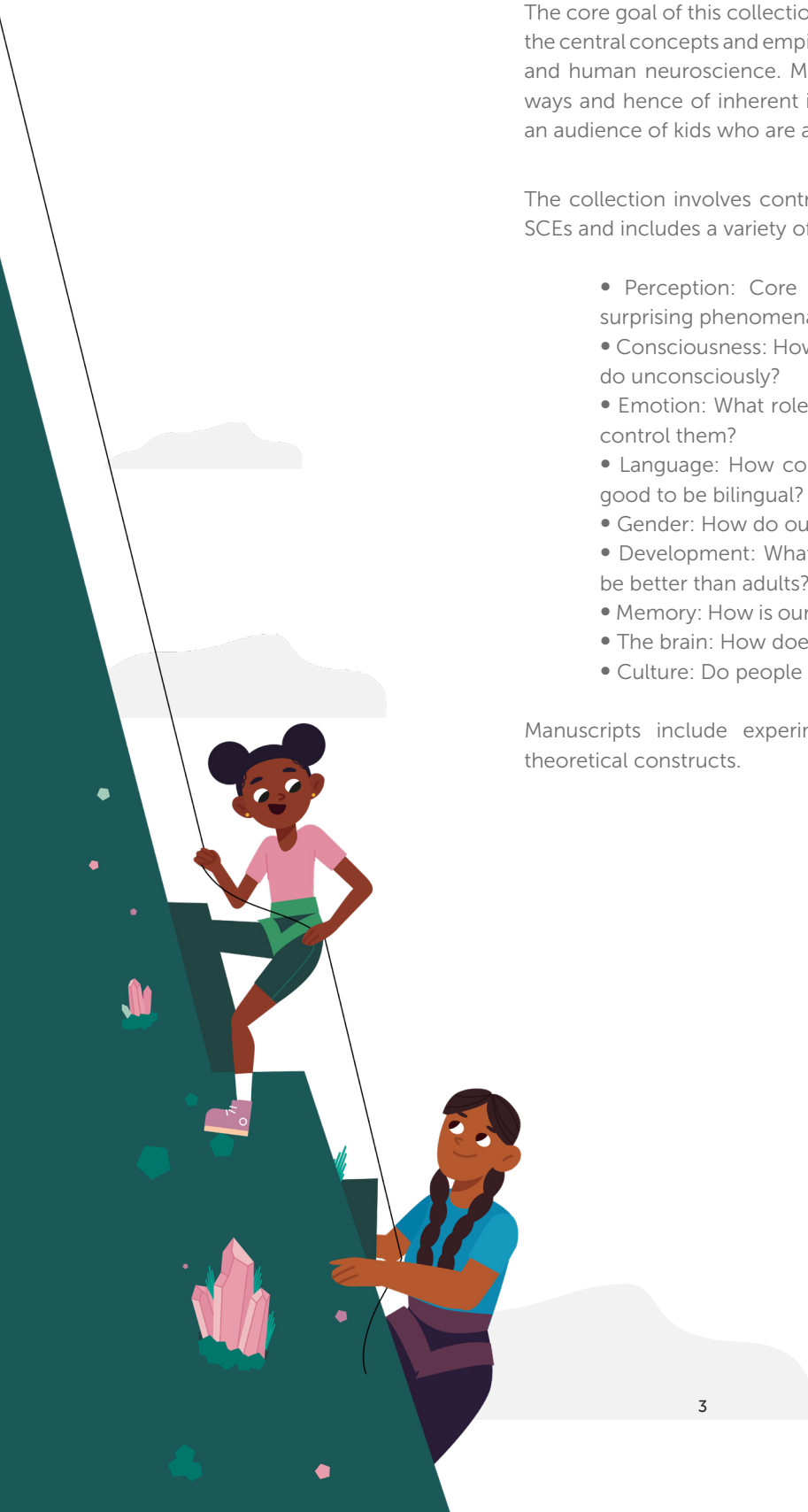
Psychology and the neurosciences attempt to understand who we are, what makes us us. At its core, this involves explaining how the biological activity of the brain produces mind — our mental states and everything that we feel. But we also need to address questions such as how our mind develops, how we interact with other people, how we perceive the world around us, how we make decisions — in short, how does our mind work?

The core goal of this collection is to offer a set of articles highlighting some of the central concepts and empirical findings in the broad domains of psychology and human neuroscience. Many of these findings are surprising in different ways and hence of inherent interest to the wider public, and in particular to an audience of kids who are at an age where one tries to understand oneself.

The collection involves contributions from different Frontiers in Psychology SCEs and includes a variety of approaches and of domains, such as:

- Perception: Core findings, but also biases, illusions and other surprising phenomena
- Consciousness: How come we are aware of ourselves? What can we do unconsciously?
- Emotion: What role do they play in decision-making? How can we control them?
- Language: How come we learn to speak without instruction? Is it good to be bilingual?
- Gender: How do our sexual preferences and identity develop?
- Development: What changes as we grow up? Can kids sometimes be better than adults?
- Memory: How is our memory organized? How do we make it better?
- The brain: How does the brain work? What can go wrong?
- Culture: Do people in different cultures see the world differently?

Manuscripts include experimental findings put in the context of core theoretical constructs.



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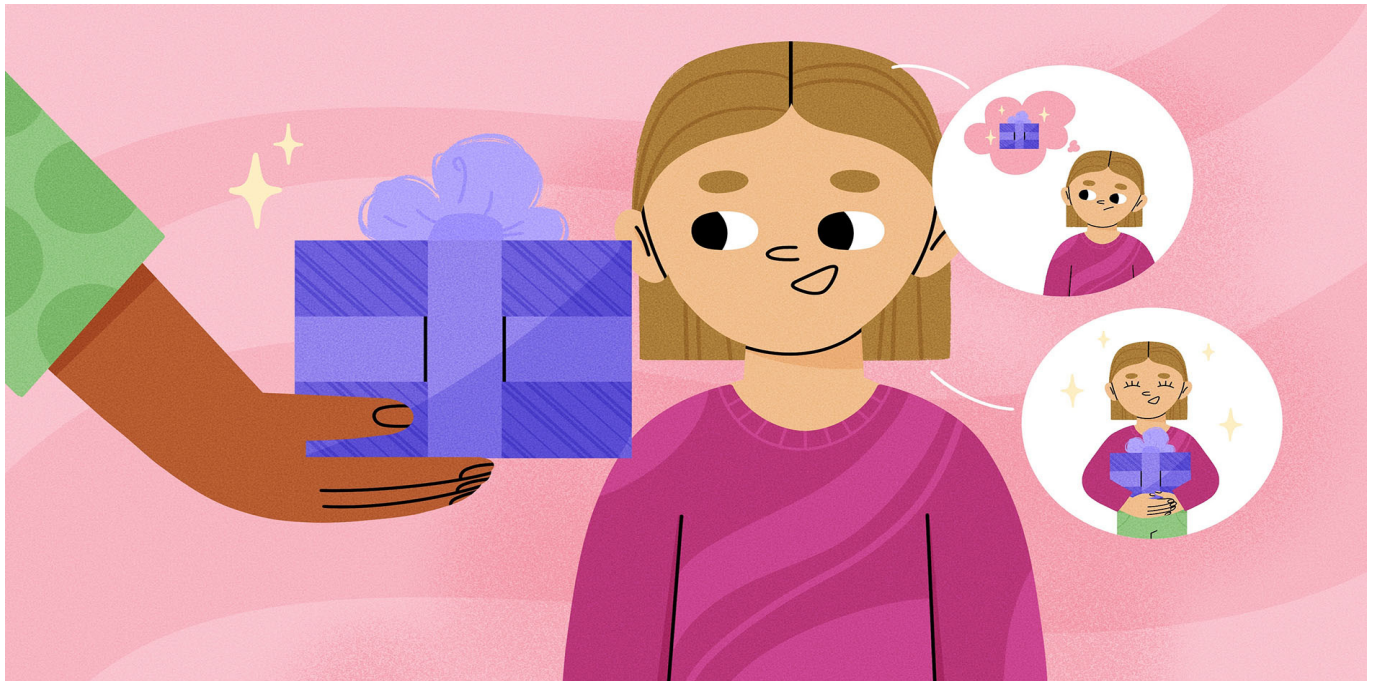
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## WHAT IS AN EMOTION?

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### YOUNG REVIEWERS:



**ANNA**

AGE: 14



**MILA**

AGE: 8

Many moments make up a day. There may be times when we feel happy and other times when we feel sad. But what is really happening when we say we “feel” something? What is an emotion? This article explores this important question. Maybe this question seems simple, but it is actually very complicated. What do we know about emotions? Why do we have emotions at all? Are emotions good or bad? By asking these questions, we join thousands of other scientists and researchers in search of answers. Since all humans have emotions, this is certainly a topic that matters to us all.

Almost 140 years ago, back in 1884, William James asked, “what is an emotion” [1]? He was an influential philosopher, historian, and psychologist. Since then, there have been hundreds of thousands of research studies, books, and journal articles about emotions. We have learned a lot, but the scientific community is still searching for a complete and widely accepted answer. Perhaps, the most accurate answer is that we do not know [2]! However, there is a lot we *do* know about emotions.



## EMOTIONS: A LONG HISTORY OF EXPLORATION AND DEBATE

Scientists have been studying emotions for many years, and they have produced many ideas about what emotions really are. Back in 1981, more than 40 years ago, researchers came up with 92 different ways to describe emotions! That means we still have a lot to learn about emotions, which is why scientists keep doing more research. Some scientists think that emotions are annoying and make us act without thinking. Other scientists, like Aristotle and Hume, think that emotions are an important part of the ability to think and make good decisions [3, 4]. There are also debates about how emotions affect our thoughts, decisions, and actions. Some people think that emotions have a big impact on us, even if we do not realize it. Others think that some emotions are good, while other emotions are bad. Despite all these differences, scientists *do* agree on many important things about emotions.

### COGNITIVE APPRAISAL

The way we think about things that happen around us and decide if something is good, bad or not important.

### AMYGDALA

The amygdala is a small part of our brain that helps us feel emotions. It is like an alarm system that gets activated when we experience something that might be important or scary. The amygdala helps us recognize different emotions in ourselves and others, like happiness, fear, or anger.

### EXPERIENTIAL

Experiential means learning by doing things firsthand rather than just reading or listening to information. Imagine you want to learn about animals. Instead of just reading a book or watching a video about them, you can visit a zoo or a farm, where you can see the animals up close, touch them, and even interact with them.

## WHAT WE KNOW ABOUT EMOTIONS

We *do* know that emotions are a really important part of being human. Emotions occur when something happens around us or when we remember something. For example, seeing a spider can make you feel scared, or remembering a fun family party can make you feel happy.

Scientists think that emotions are made up of several parts that work together. These parts have to do with both the brain and the body, and how they interact. It might not seem obvious at first, but the thinking part of the brain is involved in emotions. When we feel something, we also have thoughts about it. For example, if you are mad at someone, you might think they did something mean or wrong. This kind of thinking is called **cognitive appraisal**.

The brain and the body interact when emotions are felt. The brain controls the nerves and hormones. When we feel anxious, a part of the brain called the **amygdala** gets activated. The amygdala makes the heart beat faster and it makes the body produce stress hormones that get us ready to fight or run away. Sometimes, hormones can also make us freeze. By the way, the word “amygdala” comes from the Greek word for “almond,” because it looks like one!

Emotions also have what is called an **experiential** part. This means that when we feel emotions, we also feel something in our bodies. For example, if you see something scary in the dark, you might think it is a snake and feel afraid. Your heart might beat faster, your hands might shake, and you might feel anxious. Interestingly, the experiential part of an emotion is the only part we really notice. The other parts happen so fast that we do not realize they are happening. We cannot tell which

## EMOTIONAL SUPPRESSION

It means when we do not show how we feel. For instance, we are angry but you do not show that you are angry.

## MASKING

It means we do not show how we really feel. For instance, you are sad but you smile and hide that you are sad.

### Figure 1

When you get a gift, for example, the part of your brain that helps you feel emotions starts to work. Your brain also thinks about the gift, deciding if it is good or bad, which is called cognitive appraisal. If your brain thinks the gift is good, you might feel happy or joyful, smile, and say thank you. If your brain thinks the gift is bad, you might feel disappointed or angry; you might show those emotions, or you might pretend to be happy, to be polite, which is called masking.

part of the brain is activated or how many hormones are in the blood, but we can tell how we are feeling.

Finally, emotions also have a behavioral part. This means that emotions can interrupt and change our actions. For example, you might stop walking and start running if a dangerous animal approaches you. As one researcher put it, “emotions not only make us feel something, they make us feel like doing something” [5]. When we feel emotions, we normally show how we feel. We use our words, faces, and bodies to express our emotions. These are all behavioral components of emotions! Of course, sometimes we might try to hide what we feel. Psychologists call this **emotional suppression**. Also, we might sometimes try to show an emotion that we do not feel. An example of this is smiling when you are angry. Psychologists call this **masking**. Figure 1 explains how emotions are created.

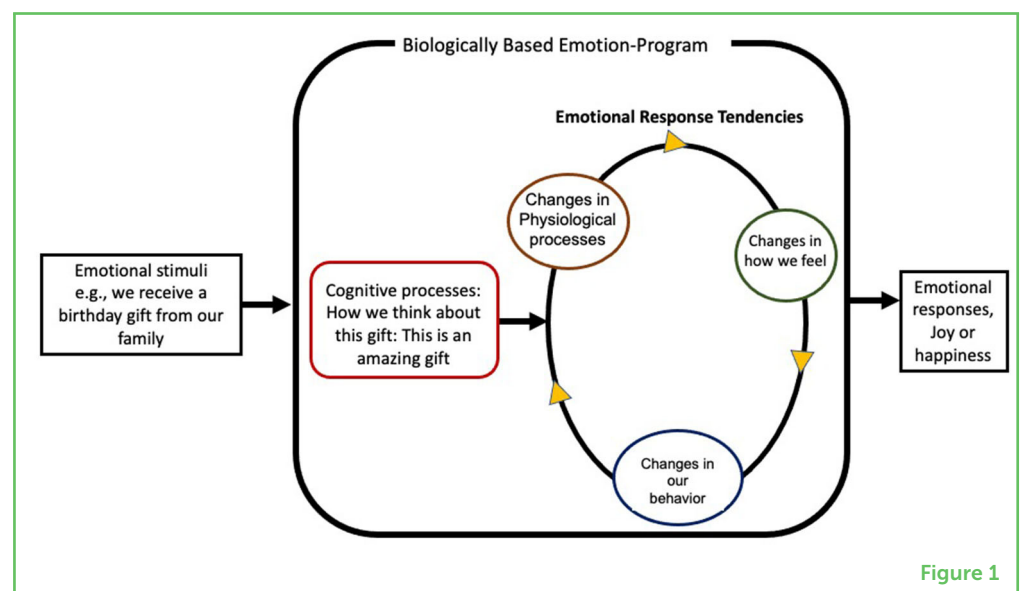


Figure 1

## WHY DO WE HAVE EMOTIONS AT ALL?

Did you ever wonder why we have emotions in the first place? The simplest answer is that we benefit from our emotions—they have important functions. Let us look at two of those functions—survival and society.

Scientific studies show that emotions exist so that humans can respond to their environments in the best possible way. Picture this: A man lives in the woods where there are many animals that are stronger than him and can attack him, like wolves. What would happen if the man could not feel scared? Fear could make him run from the animals, saving his life. It is likely that many emotions exist due to the challenges humans have faced over time. In general terms, emotions have helped us survive as a species.

## FEELING RULES

Feeling rules are the expectations that people around us have for how we should feel in certain situations. For example, imagine you are at a birthday party. The people there might expect you to feel happy and excited. They want to see you laughing, dancing, and playing. These feeling rules help us understand what emotions are considered appropriate or expected in different events or places.

## DISPLAY RULES

Display rules are the expectations that people around us have for how we should show our emotions. For example, when someone gives us good news, people might expect us to smile and laugh.

Another reason humans have developed emotion is that we are social animals who live in groups. Living with other people requires rules to govern how we live together. Emotions might help us control our social behavior. For example, emotions such as guilt, shame, and pride could guide our interactions with other people. When we feel guilty, we know that we have probably done something wrong or that our actions might have hurt another person. Because feeling guilty is unpleasant, this emotion stops us from repeating our mistakes.

Our communities shape what we should feel at certain times; these are called **feeling rules**. Communities also shape how an emotion should be expressed; these are called **display rules** [6]. For instance, feeling rules tell us that we should be sad when someone we like is hurt. Display rules tell us the “right” ways to express sadness with our faces, words, and bodies, such as crying. Therefore, understanding how to display emotions and how to read the emotions of others helps us to understand other people better. This supports relationships and social networks.

## ARE THERE GOOD AND BAD EMOTIONS?

You may wonder whether some emotions are “good” and others are “bad.” The simple answer is “no,” but the better answer is “it is complicated!”

Let us look at an example. Assume you get a low grade on one of your assignments. You are angry with your teacher. This anger means you think you deserved a better grade. You think your teacher has been unfair to you. If you remain angry for weeks, that anger will harm your wellbeing, learning, and health. So, it matters *how long* we feel something [7]. If you get so angry that your stomach hurts, then that anger is also harming you. So, the *intensity* of our emotions matters, too. Finally, if everything your teacher, your parents, and your friends do angers you, then your anger becomes an issue. So, it matters *how often* we feel a certain emotion.

You may use your anger to talk politely to your teacher. You may ask why you were not given a better grade. In this case, your anger helps you. If you yell at your teacher instead, your anger turns into a big mistake that might get you in trouble. In this case, your anger does not help you. So, it matters *how we use our emotions* and how we *regulate* them. If you use your anger to work harder and learn more, then that anger helped you to improve your performance. If your anger makes you dislike the subject and decide to stop learning it, then the anger harmed your learning.

In terms of whether an emotion is “good” or “bad,” it is also important to consider which emotions we show in which situations, meaning whether we are following the display rules of our social groups. Let us

look at another example. Assume you like to laugh and be happy. We all do! However, what happens if you are at a funeral and you laugh? Not a good idea! So, the situation and environment also matter.

Let us put it all together. If a pleasant emotion, such as joy, makes us laugh at the wrong moment, it could be bad for us. An unpleasant emotion, such as anger, that motivates us to stand up for ourselves or work harder could be good for us. In deciding whether an emotion is good for us or not, what matters is the strength of the emotion, how long it lasts, how often we feel it, how we express it, and when we express it.

## SO, WHAT IS AN EMOTION?

After all this, what exactly *is* an emotion? It is still a puzzle for the ages, a mystery of the human mind, and a fundamental part of being human. Best of all, it is an important topic for continued scientific research, and a question that applies to every one of us [8].

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## YOUNG REVIEWERS

### ANNA, AGE: 14

Hi, my name is Anna. I am a 14 year old high school student. My favorite subjects are Science, English Literature, and art. My hobbies are reading, watching TV, writing letters to friends and family, and cooking. When I grow up I will like to be an engineer and later work in fashion and get a degree in neuroscience. I am a productive person but I need to be interested in the thing I do or else I do not put a lot of effort.

### MILA, AGE: 8

I love Science, especially astronomy and archeology. I love reading and swimming and playing with my friends.

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Stephanie completed her studies in psychology at Boston College, with a particular focus in biological psychology. She is interested in how people can improve their wellbeing by connecting to themselves and their communities. Stephanie served as chair of her local cultural council for years, the mission of which was to expand access, improve education, and encourage excellence in the arts, humanities, and interpretative sciences. This sparked her love of promoting science education for kids. Stephanie currently works in data analytics at the Boston Symphony Orchestra and in her free time enjoys music, bakeries, running, and gardening.



## HOW DO WE LEARN AND WHY DO WE USE ABSTRACT CONCEPTS AND WORDS

**Anna M. Borghi<sup>1,2\*</sup>, Ilenia Falcinelli<sup>3</sup>, Chiara Fini<sup>1</sup>, Angelo Mattia Gervasi<sup>3</sup> and Claudia Mazzuca<sup>1</sup>**

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**DEREK**

AGE: 16



**GIGI**

AGE: 9

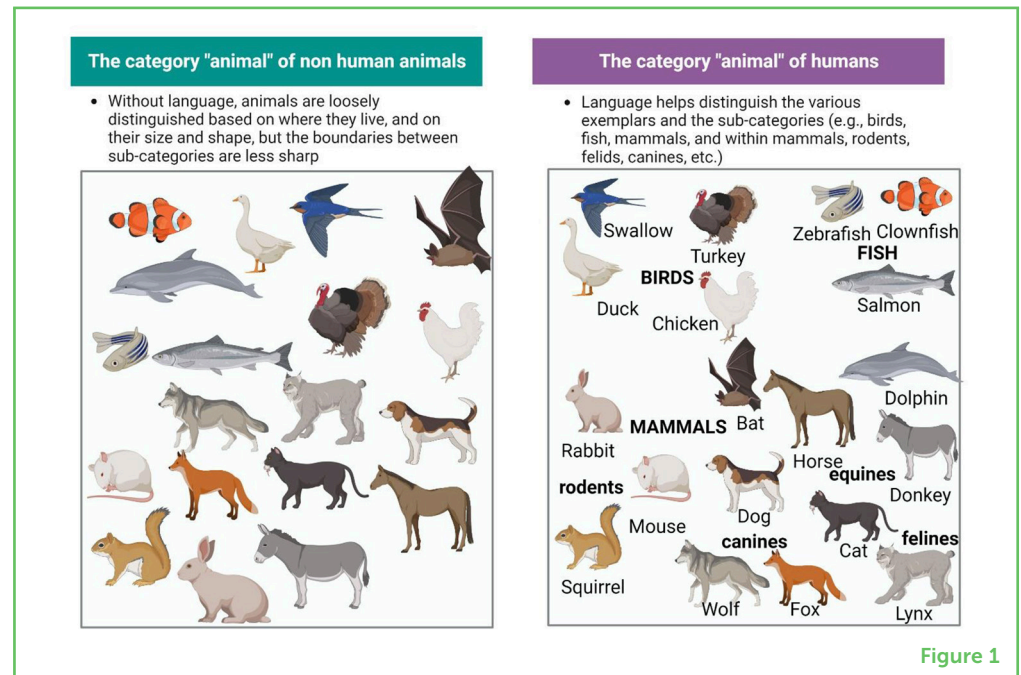
Grouping things together, also called categorizing, is fundamental for humans. We can form categories such as people, tools, and buildings. Concepts are what we mentally associate with categories. For example, we associate cats with what they look like and how they behave. “Cat” is a concrete concept, meaning that it refers to a specific animal that we can point to. Some concepts, such as “truth” or “sympathy,” do not refer to concrete objects you can point to. These are called abstract concepts. Abstract words—the words that we use to express abstract concepts—make up more than 70% of adult speech. Children use fewer abstract words because they are harder to learn. How do we learn and use abstract concepts, from emotions to numbers? Do we need more help from others to learn abstract concepts? In this article, we address these questions and discuss current research on abstract concepts.

## CATEGORIES, CONCEPTS, AND WORDS

To survive, animals must learn to categorize, which means group things together. For example, to approach prey and avoid predators, animals must have mental categories for “prey” and “predator.” Unlike other animals, humans use words to label their categories (Figure 1). For example, we use the word “animals” to refer to birds, fishes, and mammals. Naming a category makes us feel that the category members are more similar to each other.

**Figure 1**

The ability to categorize, that is, to group similar items, is fundamental for survival. For example, we humans categorize animals into “birds”, “mammals”, and “fish.” Categories allow us to make inferences about group members we may be unfamiliar with—for example, if a duck has wings, we “infer” that other birds have wings, not that horses have wings. Even if we have never seen a lynx, we know it will probably have whiskers like other cats because we categorize it as a feline. Animals and humans have different categories because we use language. Language helps create subcategories (e.g., “mammals” vs. “birds”) and make their members more similar (Figure created using Biorender.com).



**Figure 1**

Categories also allow us to extend our knowledge by making inferences. For example, knowing that robins are birds tells us robins probably fly, have beaks, and lay eggs. Finally, words that name categories help people interact and communicate—we can speak of birds and understand each other, even when there are no birds around to point to. Concepts, which we express using words, are the mental aspects of categories: they consist of what we know about objects and entities, the brain areas that are activated when we use them, and the actions we perform when thinking of them. Depending on the concept we are thinking about, various areas of the brain might be activated. For example, when thinking of the appearance and chirping of robins, we might activate the areas of the brain responsible for sight and hearing. Similarly, when thinking of hammers, we might imagine their color, shape, where we might find them, and the actions we typically perform with them. Hence, thinking of hammers activates areas of the brain involved in vision and in planning and controlling movement.



## CONCRETE CONCEPTS

Ideas that typically refer to single objects or animate beings, like “hammer” or “cat.”

## ABSTRACT CONCEPTS

Ideas that do not refer to single objects but instead are more complex and detached from the senses but evoke inner bodily signals and emotions more. Examples include “justice”, “democracy”, or “thinking.”

## ABSTRACT WORDS

Words used to express abstract concepts.

### Figure 2

Differences between concrete and abstract concepts. **(A)** Members of abstract concepts differ more. **(B)** Abstract concepts activate the five senses less. **(C)** Abstract concepts activate more feelings and bodily signals. **(D)** Abstract concepts are harder to imagine. **(E)** Children learn abstract concepts through language. **(F)** People trust their knowledge about abstract concepts less and need others more to learn them. **(G)** Abstract concepts vary more across contexts, cultures, and languages (Figure created using [Biorender.com](https://www.biorender.com/); images from [pixabay.com](https://www.pixabay.com/) and [flickr.com](https://www.flickr.com/)).

## CONCEPTS: ABSTRACT AND CONCRETE

Both “robin” and “hammer” are **concrete concepts**, meaning that we could point to an actual robin or hammer. In this article, we focus instead on **abstract concepts**, i.e., concepts expressed by **abstract words** like “fantasy,” “thinking,” “shame,” and “addition.” (see Figure 2). Abstract concepts are interesting because, unlike concrete concepts, their meaning is not entirely set and is often open to discussion. Generally, abstract concepts do not refer to a single object but to multiple components that interact and have complex relationships. For example, the concept of “justice” might evoke a judge, a courtroom, and a person being judged.




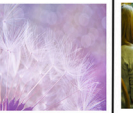





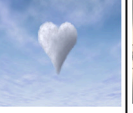



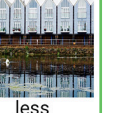
	A	B	C	D	E	F	G
	Commonalities and differences	Five senses	Inner bodily signals & emotions	Imagination of the concept	Learning age and modality	Social metacognition	Variability
ABSTRACT	 few common properties, dissimilar members	 activate the five senses less	 more inner bodily signals and emotions	 harder to imagine	 learned later, and through language	 lower confidence and more need of others	 more variable across contexts and cultures
CONCRETE	 many common properties, similar members	 activate the five senses more	 less inner bodily signals and emotions	 easier to imagine	 learned earlier, and through perception	 higher confidence and less need of others	 less variable across contexts and cultures

Figure 2

If you think abstract concepts are just more difficult to imagine than concrete objects and do not involve our five senses and the areas of the brain that control them, then you are wrong! Abstract concepts *do* involve the five senses, although sometimes less than concrete concepts do. Abstract concepts can also generate feelings and inner bodily responses, sometimes even more strongly than concrete concepts do. This is particularly true for abstract concepts that convey emotions, such as “love” and “optimism.”

Along with abstract concepts, we also have abstract words. Abstract words have their own uniqueness. Children learn them later than they learn concrete words, typically by using language and words to explain abstract words, rather than simply pointing at an object. Importantly, people tend to feel less confident about knowing the meaning of abstract words, they consider the meanings of those words more open

to debate or discussion, and they believe that they need help from others to understand their true meaning [1, 2].

## WHY ARE ABSTRACT CONCEPTS INTERESTING

Scientifically, abstract words and the concepts they express are very interesting. We call abstraction our ability to group things forming more general and specific categories (e.g., “animal” vs. “Siamese cat”). This is different from our capability of learning and using abstract concepts (e.g., “justice” and “beauty”), which we call abstractness, and on which we are focusing in this article. Hence, abstraction and abstractness are linked but are different. Using abstract concepts and words is a very sophisticated ability, and a large part of adult speech—up to 70%—is composed of abstract words. So, it is very important to understand how we learn and use abstract concepts. Abstract words are sometimes so difficult to learn and use properly that they create or influence our relationships with others. For example, people often ask others to explain the meaning of abstract words, and this can generate interesting discussions!

## TO LEARN ABSTRACT CONCEPTS, WE NEED OTHERS

Researchers think that to learn abstract concepts, people need others more than they do when they learn concrete concepts [1]. Why is this the case? Children generally learn concepts by noticing similarities among objects, making mental connections, and forming categories. For example, we might form the concept of “table” by noticing the similarities between various tables: a flat surface and four legs. Although there are wooden tables, plastic tables, garden tables, and kitchen tables that all differ to some extent, all tables look similar. As another concrete example, think of the category “things to take on a trip.” This category might include a mix of objects that differ in shape, color, size, and texture: books, clothing, bags, and maps, for example. Although these things do not look similar, they are all objects that can be used for a common goal or in a common setting (traveling).

The learning process is much more difficult for abstract concepts. Think of the abstract concept “justice.” Things that belong to the concept “justice” are not similar in terms of what they look like, the sounds they produce, the tastes they have, or any other quality. In addition, the members of “justice” might refer to different goals or situations, for example, to a courtroom where a judge must make a verdict, or to a group of friends who want to share some candy equally. To learn what kinds of things make up the concept of “justice,” we need others to explain to us what justice means. People might have quite different ideas about what “justice” or other abstract concepts mean, and this can lead to discussions in which ideas are compared or even



debated. Sometimes, discussions about abstract concepts can even change our minds about what we think they mean (Figure 3).

### Figure 3

Discussion of the meaning of abstract concepts, such as justice, is necessary for a shared understanding of what the concepts mean (Image from pixabay.com).

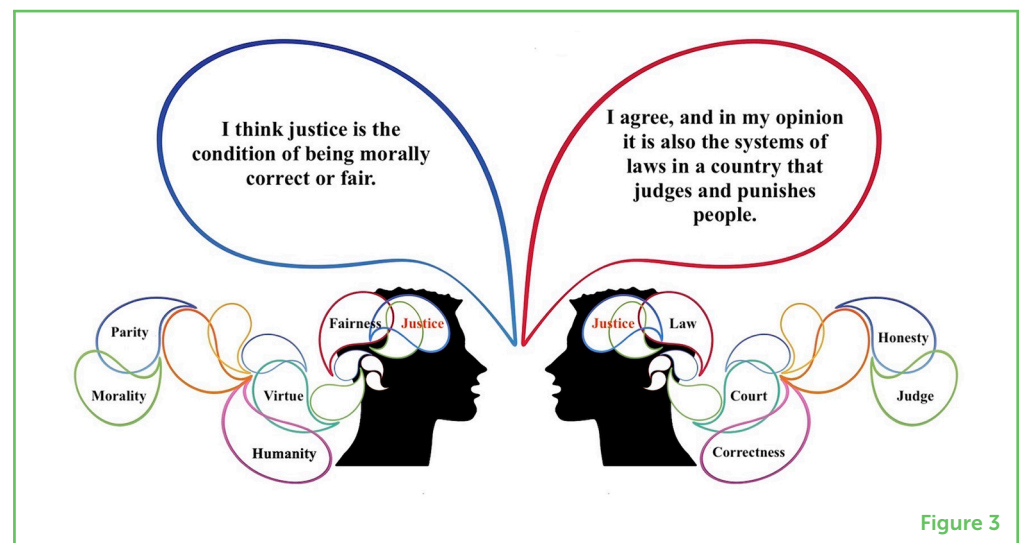


Figure 3

### INNER SOCIAL METACOGNITION

An inner process that involves “talking to ourselves” to figure out what we know about a concept. For example, we might ask ourselves, “Do I really know the meaning of “democracy”?”

### COGNITION

The process of acquiring knowledge using our senses and experience; it includes paying attention, perceiving the world, memorizing, reasoning, and using language.

### METACOGNITION

The process of thinking about our thoughts and reasoning and evaluating them. For example, using metacognition we might decide that we have good memory, or that our knowledge is insufficient.

Studies on children show that to learn abstract concepts, language and the help of other people are particularly important. Other people help children to learn by using words and providing explanations. For example, hearing a single word, i.e., “freedom,” helps us keep together different experiences related to freedom, such as running on a field, exiting from prison, and having no limitations. Because the words and explanations of others are crucial to learning abstract concepts, learning these concepts might increase the sense of social connectedness among people. Maybe abstract concepts emerged in language over time *because* they increase social connectedness, which helps us survive as a species!

### TO UNDERSTAND AND USE ABSTRACT CONCEPTS, WE NEED OTHERS

Recent studies support the idea that not only do we need others to *learn* abstract concepts but also to fully understand and use them. Imagine a conversation with someone who uses an abstract word like “desire.” Because of the complexity of this concept, you might be more uncertain about the word’s meaning than if the person mentioned “cats.” Therefore, you might have to move through two main phases to understand the abstract concept.

Phase 1: You might talk to yourself (in your head) to search for the word’s meaning, maybe even as if you were two different people (dialogic inner speech). For example, you might ask yourself, “What does this word mean?” This process is called **inner social metacognition**, that concerns both **cognition** and **metacognition**. It involves examining your knowledge through a process that is both inner and social [3]. If the inner search is not successful, meaning

## SOCIAL METACOGNITION

The process of depending on others for information about concepts. It could involve simply asking them ("What does democracy mean?") or debating the meaning with them ("What do you mean by democracy?").

## KNOWLEDGE OUTSOURCING

The reliance on other people, possibly experts in a domain, to enrich our knowledge. For example, to learn the meaning of "democracy," we would refer to an expert in politics.

you still do not understand the meaning of the word, the next phase can help.

Phase 2: If you do not find a response by inner social metacognition, you can ask someone who understands the word's meaning better than you do, or you can debate the word's meaning with others. This process is called **social metacognition**. In this phase, you search for knowledge elsewhere and rely on the knowledge of other people (**knowledge outsourcing**). There are three basic ways to do this. First, you might not know the meaning of a word and simply ask others what it means. For example, children might ask their teacher what the word "philosophy" means. Second, you might want to know whether others have the same thoughts about the meaning of a word as you do. So, you might ask others what the word means to them. For example, does "desire" mean the desire for food (hunger), desire for a person (love), or desire for knowledge (curiosity)? The meaning of abstract words can evolve and change across a person's lifespan, so the meaning of "desire" can differ between children, adolescents, and adults. Third, you might want to define a word with other people. Imagine you are a scientist and want to come up with a clear definition of "representation." You might debate its meaning with colleagues to arrive at a shared definition. Asking others what an abstract concept means could lead to discussion or debate about the word's meaning, which can help people come up with a shared definition.

Which scientific evidence supports these processes? First, we have found that people feel more uncertain about what abstract concepts mean, feel that they need others to learn them, and think that these concepts are so complex that they do not fully trust even the knowledge of experts [2]. Second, when people respond to sentences featuring abstract concepts, they use more expressions signaling doubts and uncertainty, ask more "why" and "how" questions, and tend to continue the interaction longer [4]. Third, when people receive help from others to guess which concept an image refers to, they feel more socially connected, i.e., they move at the same time and speed, as others who gave them suggestions about abstract than concrete concepts. It is more difficult to see an image and guess that it represents "beauty" instead of "table," so others are more important in the first case [5]. Finally, evidence shows that, when using abstract concepts, their mouth motor system is more involved [6]. This suggests that people talk to themselves to find the possible meaning or, if they realize they do not know what the word means, they do so to prepare themselves to ask others the word's meaning or to discuss it with them.

## CONCLUSION: USING ABSTRACT CONCEPTS MIGHT STRENGTHEN OUR RELATIONSHIPS

Abstract concepts include category members that can be very different from each other, and their meaning is not fixed and stable

but varies a lot depending on the situation and the person who uses them. So, to learn abstract concepts, we rely more on others than we do when we learn concrete concepts and when we use abstract concepts, they can easily lead to discussion or debate. For this reason, abstract concepts might contribute to creating stronger social bonds with others. Many questions are open, though. There might be different kinds of abstract concepts, for example, philosophical-spiritual concepts, that relate to deep questions about life and the nature of knowledge (for example, "religion," "moral," and "destiny"), emotional and social abstract concepts ("love" and "shame"), and abstract concepts related to space, time, and numbers ("area," "day," and "sum"). Do the different types of abstract concepts strengthen our relationships in different ways? Do concepts that we have different opinions about, like politics, increase our sense of social connectedness or not? How do we form and use concepts, such as gender, that include both biological aspects and aspects that vary depending on the place and society in which people live? How do we learn scientific and technological concepts? Also, how do abstract concepts change across situations, languages, and cultures? Continued study of abstract concepts is important because they constitute an important part of how we think, how we speak, and how we interact with others.

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## YOUNG REVIEWERS

### DEREK, AGE: 16

Hi, I am Derek, and I currently live in Vancouver, Canada. I love science, but outside of that, I can be found staring at a map, trying to wrap my head around math problems, desperately attempting to memorize ancient vocabulary moments before a test, or hitting the buzzer far too late in quiz competitions.

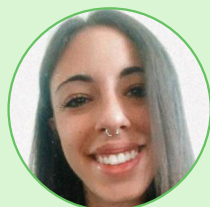


**GIGI, AGE: 9**

My name is Gigi. I play piano and like art. My favorite thing to do is art and crafts. I have a tuxedo cat named Athena. And my favorite color is yellow!

**AUTHORS****ANNA M. BORGHI**

I am a researcher and a teacher of cognition. I work in Rome, a city I love. Since adolescence, I have always been interested in language as a tool for thinking and interacting. In the Body, Action, Language Lab (BALLab), we study bodily and social experiences that objects and words evoke, especially abstract words, like “freedom.” We use various experimental methods, including asking people to list and rate word features, measuring response time, eye and hand movements, and activated brain areas, and simulating language in robots. Aside from research, I enjoy being with my children, swimming, singing, and reading novels. \*[anna.borghi@gmail.com](mailto:anna.borghi@gmail.com)

**ILENIA FALCINELLI**

I am a doctoral student in psychology and neuroscience at Sapienza University of Rome. I am interested in studying how people represent concepts referring to nature (such as “forest”) and ecological issues (like “climate change”). I am convinced that investigating this topic can help us to behave better toward our planet. For this purpose, I use various experimental methods, ranging from asking people to produce free associations for given concepts to investigating the time required to process words. I also investigate the brain waves occurring during the processing of words and concepts, using electroencephalography (EEG).

**CHIARA FINI**

I am a researcher and a psychologist at Sapienza University of Rome. I was a child when I realized that I wanted to be a psychologist. However, I did not plan to be a researcher—that happened during my internship after I got a master’s degree in neuropsychology. At that point, I discovered how exciting it was to study human behaviors. My research interests are about the role of the body in shaping our mental life: how much our motor system is involved in brain processes such as perception, language, and social interactions. Is our body a bridge through which we can connect to others?

**ANGELO MATTIA GERVASI**

I graduated with a degree in psychology from the University of Bologna, and I moved to Rome to begin a Ph.D. in neuroscience at Sapienza University, in collaboration with the Lyon Neuroscience Research Center. Since my childhood, I have always loved sports, and I developed an interest in the effect of sports on the brain. For this reason, I study the brain mechanisms underlying our actions. In particular, I focus on the interaction between action and language. During my free time, I love playing tennis and football, watching matches, and taking pictures of the gorgeous monuments of Rome.



**CLAUDIA MAZZUCA**

I am a postdoctoral researcher at Sapienza University of Rome. I have always been fascinated by the capability of language to shape and create reality, so I study the interplay between language(s) and cognition. Abstract concepts are where this magic happens in the most exceptional way, as they require language to exist. So, I try to understand the role that the body and social factors play in the representation of abstract and concrete concepts across languages and cultures. I am passionate about science overall, and to this end I try to practice and communicate principles of open science.



## WHAT IS CULTURE?

**Akshata R. Naik<sup>1</sup>, Stephanie Baker<sup>2</sup> and Changiz Mohiyeddini<sup>1\*</sup>**

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<sup>2</sup>Boston Symphony Orchestra, Boston, MA, United States

### YOUNG REVIEWERS:



**ARITRO**

AGE: 14



**DAVID**

AGE: 12

In this article, we will explain what culture is and why it is such a complex concept. Culture encompasses many aspects of human life, such as shared beliefs, values, customs, and behaviors. Cultures often vary by region or location, and they can change and evolve over time. Socialization, the process of learning to adapt one's thinking, behavior, skills, and attitudes to fit into a society, is an important way passed on between people as they develop from childhood into adulthood. Finally, we will discuss an important psychological process termed as acculturation, which describes how immigrants and others who move to new locations respond and adapt to new cultures. Studying culture is important especially in today's globalized world where our interaction is not just limited to people from our own culture. Understanding different cultures helps us admire and approve of people belonging to a different cultural system than our own thus fostering collegiality.

## CULTURE

The way of life, traditions, and customs that a group of people share, including their beliefs, values, norms, and how they treat each other.

## SOCIALIZATION

Is a process through which we learn certain behaviors, beliefs, and values of the society in which we live in.

## WHAT IS CULTURE?

Do you often notice that you have certain similarities with other kids who go to your school? Or maybe you have noticed that your family does things differently from some of your friends' families? These similarities and differences could be anything from the restaurants you go to, the type of music you enjoy, the movies you watch together... and the list goes on. Although many of these similarities and differences are due to personal choice, as individuals we are influenced by the people, society, and practices that surround us, which, taken together, are called our **culture** [1].

Culture is often based on a particular region or specific location (Mediterranean, East Asian, North European, etc.). Over the course of history, humans all over the world have created many cultures, which have shaped what people think, feel, wish, value, and how they behave. Culture is a very broad and complex concept that includes many aspects of human existence and daily life [1]. It refers to the shared beliefs, values, traditions, social norms, and behaviors of a group of people who share the same living environment in a specific region of the world.

Culture encompasses key aspects of a society, including language, education, religion, government, and the identity and personality of the people who are part of that culture. The United Nations Educational, Scientific and Cultural Organization's defines culture as "the set of distinctive spiritual, material, intellectual and emotional features of society or a social group, that encompasses, not only art and literature but lifestyles, ways of living together, value systems, traditions and beliefs" [2]. Simply put, this definition of culture also emphasizes that culture is reflected in both physical elements of a group or society, such as cuisines, fashion, music, dance, literature, or architecture, and also in the non-physical elements such as customs, traditions, beliefs, and values.

Culture does not stay the same—it changes and evolves over time. New beliefs, values, customs, traditions, and practices continually replace older ones. The process of cultural change is faster for societies that are open to outside influences, such as societies that engage in cultural exchange activities with other cultures (for e.g., study abroad programs, hosting an international student), trade with many other countries, or have high levels of immigration.

A key characteristic of culture is that people are not born with it. Culture is learned starting at birth, and the learning continues throughout an individual's life. Culture is passed down from one generation to the next through **socialization**. Socialization refers to a lifelong process by which we learn the values, norms, and behaviors that are appropriate for the society we live in [3]. Socialization occurs through interactions with our family members, friends, teachers, and

role models, and also through TV, the internet, and other forms of communication. Socialization helps our culture to shape our personalities and our identities. Additionally, culture gives people a sense of belonging and fitting into the world. It shapes the way people understand the world and helps them to find stability in their lives, even if they are living in a rapidly changing world.

It is important to emphasize that culture is not the same across any one society. There are subcultures within a larger culture, each with its own distinct beliefs, values, and practices. For example, within a country, there may be unique regional cultures, ethnic cultures, and age-related cultures.

## CULTURAL PSYCHOLOGY VS. CROSS-CULTURAL PSYCHOLOGY

### CULTURAL PSYCHOLOGY

Is a branch of psychology that explores how our thinking, feeling, and actions are shaped by our culture.

**Cultural psychology** is a branch of psychology that studies how culture shapes and impacts human lives. The aim of cultural psychology is to determine what culture is and to identify how it affects people. As most psychological research has focused on cultures and societies that are western, educated, industrialized, rich, and democratic [4], a key goal of cultural psychology is to include a broad range of cultures and enable them all to contribute to the development of psychological theories that can explain *all* human behavior and experiences. Therefore, cultural psychology examines how cultural factors such as values, beliefs, and social norms shape individuals' thinking, emotions, and behaviors. A key assumption of cultural psychology is that culture shapes the way we think [5] or express our emotions (by painting, writing poems, or composing music, for example) and these things, in turn, shape the cultural environment and therefore impacting it. Put simply, we are shaped by our culture and in turn we shape the culture of our society.

### CROSS-CULTURAL PSYCHOLOGY

Is a branch of psychology that studies how people with different cultural background can think, feel, and behave like each other or unlike each other.

**Cross-cultural psychology** is a branch of psychology that compares the behavior, thought processes, emotional processes, and experiences of people from different cultural backgrounds [6]. For instance, cross-cultural research has established that the emotions we feel, as well as how we regulate them and express them, are related to our cultural background [7]. In some cultures, for example, it may be considered appropriate to express one's emotions openly, while in other cultures it may be considered appropriate to keep emotions hidden. By studying such cultural differences, cross-cultural psychologists can gain a better understanding of differences in human behavior based on differing cultural backgrounds. This knowledge is very important so that people can understand how to behave appropriately in places with cultures different from their own. In general, cross-cultural psychology aims to identify universal psychological processes that are *shared* by people from all cultures, as well as to identify cultural variations in psychological processes.



## ACCULTURATION

When a person from one culture learns about a new culture, and their actions and thoughts become more like the new culture. This often happens when people move to a different place.

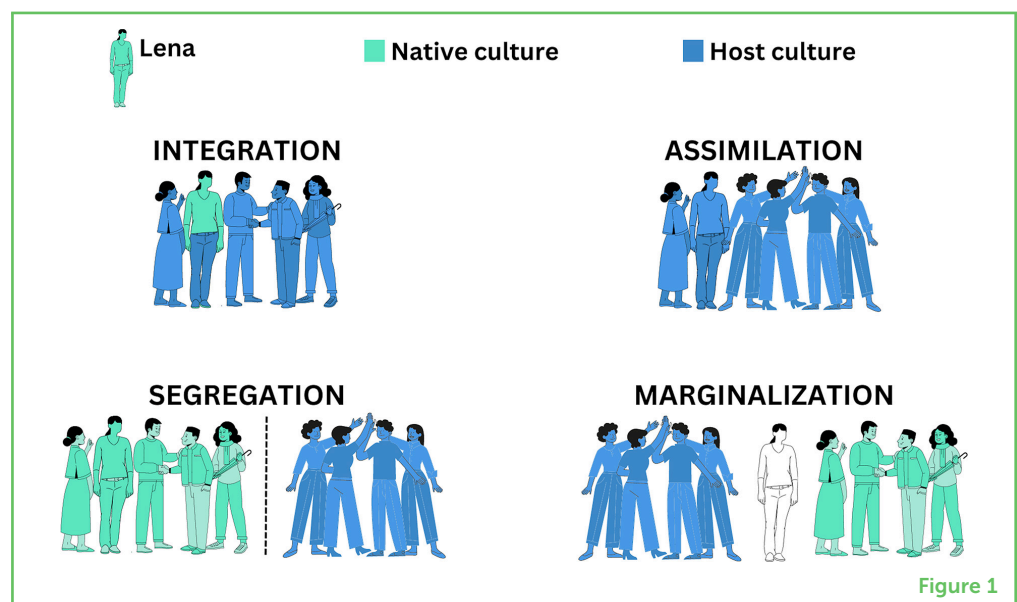
**Figure 1**

Psychologist, John Berry explained the four acculturation patterns in people (for e.g., Lena) adapting to living in different cultures: Lena grew up in one culture but now lives in a new place with a different culture termed as “host culture.” Green represents her native culture, while blue represents host culture. Lena’s acculturation is illustrated through four different patterns. When she mixes her green and blue culture, it’s called “integration.” If she wears only blue clothes, she portrays assimilation. Lena sticks to her green roots with green-only clothes in “segregation.” But when she doesn’t feel like she belongs to either culture and wears whatever she wants, that’s “marginalization.”

## ACCULTURATION: AN IMPORTANT TOPIC IN CROSS-CULTURAL PSYCHOLOGY

**Acculturation** refers to the social and psychological process that immigrants and other cultural minorities face when they attempt to find balance between their own culture and the culture of their new society, by adapting to new social norms, values, customs, rules, and expectations.

A psychologist named Berry [6] came up with four ways that people might respond to a new culture. In **Figure 1**, Lena is an example of someone who grew up in one culture which is her native culture but now lives in a new place with a different culture (called the host culture). Lena’s acculturation could have one of four patterns:



**Figure 1**

**Integration:** Lena learns new things from her host culture but keeps parts of her native culture. She has found a way to mix both cultures together. An example of integration could be when students from different backgrounds and cultures work and play together in the same classroom, participating in activities as a diverse group.

**Assimilation:** Lena completely adopts all norms, traditions, and behaviors of the host culture and probably interacts only with people from the host culture. A real-life example of assimilation would be a family moving to a new country, where they learn the language, customs, and traditions of their new home. However, they give up all important aspects of their own culture such as language, traditions, or food.

**Segregation:** Lena keeps her native culture and refuses to adapt to the host culture. She only interacts with people from her native



culture. A real-life example of segregation would be a neighborhood or community where individuals of the same ethnicity predominantly live together, resulting in limited interactions with people from other backgrounds.

**Marginalization:** Lena does not feel like she belongs to either culture. She does not want to be associated with either her native or the host culture. A real-life example of marginalization would be an individual who experiences rejection or exclusion due to their disabilities or religion. Imagine if someone was told they were not religious enough in their own culture, and then in the new place they moved to, people said they were too religious. This can make them feel like they don't fit in anywhere, just like Lena. It is like being stuck in the middle, not belonging to either group, and it can be tough for anyone, especially for kids.

Research on acculturation has shown that it is challenging and can cause a tremendous amount of stress and related physical and mental health issues—especially for segregated or marginalized immigrants. Cross-cultural research has also shown that the reason a person immigrates is a key determinant of how much stress they feel during acculturation. For example, refugees who are forced to leave their native culture for safety reasons experience roughly 50% more acculturative stress than do immigrants who are not in danger in their old culture but still make a choice to leave. Cross-cultural psychologists use these findings to develop ways to help immigrants and other cultural minorities navigate the acculturation process more smoothly.

**Let's talk about two kinds of psychology:** cultural psychology and cross-cultural psychology. Cultural psychology says that our experiences and actions are mostly shaped by our own special culture. So, when we compare how people from different cultures act, we must be careful because they might act differently because of their culture.

On the other hand, cross-cultural psychology looks for things that are the same for everyone, no matter where they're from. It tries to find out if there are feelings and actions that people all around the world have in common. But it also looks at how cultures can make these things a bit different. So, it's like exploring what makes us the same and what makes us unique because of where we come from.

## GLOBALIZATION

The connection of people across the world to each other that makes us feel closer. This can happen through things like technology, trade, and culture.

## WHY UNDERSTAND OTHER CULTURES?

Now that you understand culture and cross-cultural psychology, you may ask, "Why do we spend so much energy trying to understand culture?" The short and simple answer is **globalization**. Look around you. Do you find that your school, classroom, or sports team has

## DISCRIMINATION

When a person is treated unfairly or differently because of their race, gender, religion, or other characteristics. This behavior is unfair and very hurtful.

## PREJUDICE

When a person has unfair opinions about a group of people or judges a person based on things like stereotypes or biases. This is also not right and unfair.

people from diverse cultures? The answer is most likely yes, and this is true for many other aspects of society besides school. To thrive in a globalized world, we must understand each other's cultures.

When people from different cultures share the same living environment, workplace, school, classroom, or sports team, it is natural to see differences in customs, values, and beliefs. These cultural differences can often lead to misunderstandings and conflicts if not handled with respect, appreciation, and open-mindedness. **Discrimination** and **prejudice** [8] often stem from a lack of understanding of cultural diversity. When people respect cultural differences and value cultural diversity, they are empowered to communicate and interact with one another successfully and to build positive relationships with individuals from other cultural backgrounds. Historical examples and scientific research show that understanding and respecting each other's cultures is a key condition for a peaceful, prospering society that contains people with diverse cultural backgrounds.

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## YOUNG REVIEWERS

### ARITRO, AGE: 14

Hello! I am 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.

### DAVID, AGE: 12

I am 12 years old and really like to read, to learn and to write. I also enjoy to listen Hip-Hop music, to build Legos, and to watch comedy and horror movies. Currently, I do not do many sports but I would love to learn martial arts, I used to swim and wrestle. I also try to collect comic books of every genre.

## AUTHORS

### AKSHATA R. NAIK

Akshata went to college in Mumbai, India and moved to Michigan, United States where she got her Ph.D. degree in physiology. She currently teaches medical students at Oakland University and enjoys teaching middle and high-school kids about science during summer. Akshata loves to read, write, paint, dance, and travel with her husband and her kids.

### STEPHANIE BAKER

Stephanie completed her studies at Boston College in Psychology with a particular focus in Biological Psychology. She is interested in how people can improve their wellbeing by connecting to themselves and their communities. Stephanie served as chair of her local cultural council for years whose mission was to expand access, improve education, and encourage excellence in the arts, humanities, and interpretative sciences. This sparked her love of promoting science education for kids. Stephanie currently works in data analytics at the Boston Symphony Orchestra and in her free time enjoys music, bakeries, running, and gardening.



**CHANGIZ MOHIYEDDINI**

Changiz is a full professor and director of behavioral medicine and psychopathology at Oakland University William Beaumont School of Medicine. He received his degrees from Germany. Changiz's teaching portfolio includes behavioral medicine, child and adult psychopathology, brain and behavior, clinical-health psychology, personality psychology, psychological assessment, counseling psychology, and advanced quantitative and qualitative methods. His research focuses on biological, cognitive, and behavioral indicators of resilience, trauma, and emotion regulation. The primary objective of his educational research is to improve students' wellbeing, engagement, success, and learning experiences, sense of inclusion, and retention.

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## BRAIN CHEMICALS THAT MAKE US HAPPY OR SAD

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### YOUNG REVIEWERS:



C.R.

AGE: 9



JIA

AGE: 15

Every day, you experience many kinds of emotions that affect the way you think and act. However, you probably never stop to think about why you feel this way: teeny-tiny chemicals are responsible. These chemicals, called neurotransmitters, can control your mood and activity. Your body is made up of many small parts called cells and, using dozens of types of chemical signals called neurotransmitters, cells communicate with each other. It is as if the cells are “passing notes” around, sending messages back and forth from the brain to the rest of the body. Learning more about the neurotransmitters flowing throughout the body and how they work in cell communication can help us understand more about how our emotions work and it can also help scientists create medications for people with certain mental health conditions. In this article, we discuss three major neurotransmitters and the emotions they cause.



## WHY DO YOU FEEL?

Think back to a time when you felt excited and happy. Now, remember a time when you felt sad or disappointed or even angry. Have you ever thought about why you felt those things or why your body reacted the way it did when you experienced those emotions? You can thank some itty-bitty chemicals produced by nerve cells that are at work all throughout your body.

### NEURONS

Cells that make up the brain, spinal cord, and nerves. They consist of dendrites, a cell body, and an axon.

### DENDRITE

Short branched structures on neuron cell bodies that receive chemical signals from other cells.

### AXON

The long thin part in the middle of a neuron that sends signals from the cell body to the axon terminal, releasing chemicals that lead to signaling in other neurons.

### SYNAPTIC GAP

The space between the end of one neuron and the start of another neuron, which neurotransmitters cross for cell-to-cell communication.

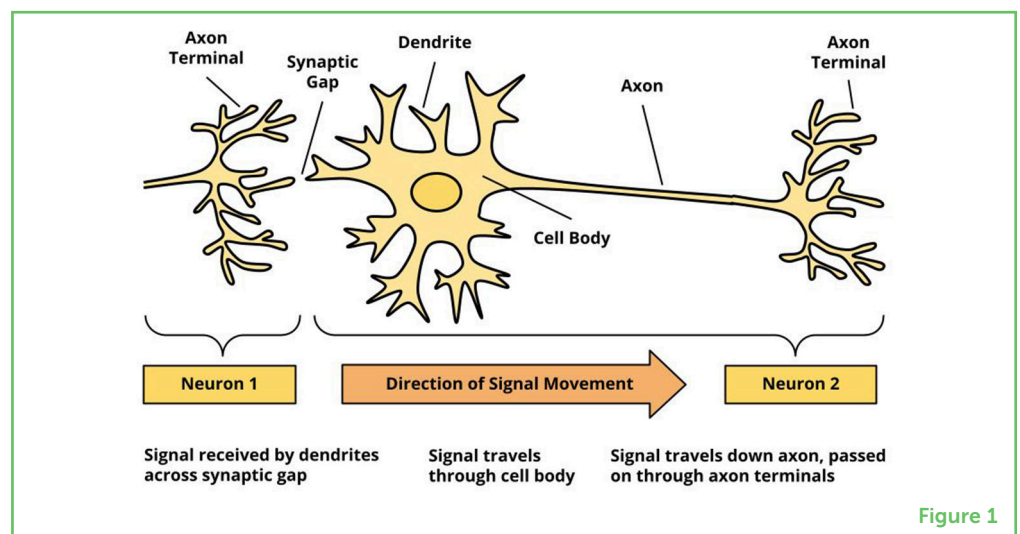
### Figure 1

Neurons consist of three main structures: dendrites, the cell body, and the axon. Dendrites receive signals from the environment or from other cells. The signals travel through the cell body and then down the axon, which passes the message on to more neurons across the synaptic gap.

## NEURONS CONTROL YOUR BODY

Cells are the basic building blocks of life. Your body is made up of trillions of cells! Nerve cells (also called **neurons**) are one of the body's many cell types, and they have two main functions: to sense the outside world and to control your body's responses to the outside world. How do neurons do this? By working together!

Neurons, which are found in the brain, spinal cord, and all other organs, communicate with one another using chemical signals to relay information throughout the body. They do this through their unique structure (Figure 1). The cell body is the "main area" of the neuron. **Dendrites** are short branches extending from the cell body that *receive* chemical signals from other cells. The **axon** is a long, thin fiber extending from the cell body that branches out at the ends. The very ends of the branches are called axon terminals and they *release* chemical signals into the small space between two neurons, which is called the **synaptic gap**. So, in summary, a neuron receives signals through its dendrites, the signal moves through the cell body and down the axon, and is passed on at the axon terminals, so that another neuron can receive it. Together, neurons can control many things about us, including our emotions [1].



## NEUROTRANSMITTERS

Chemical messengers that transfer signals from one nerve cell to another.

### Figure 2

Details of how neurotransmitters work. **(A)** An electrical signal travels down the presynaptic neuron to the axon terminal, causing neurotransmitters to be released from vesicles. **(B)** Neurotransmitters cross the synaptic gap. **(C)** Neurotransmitters bind to the receptors on the dendrites of the postsynaptic neuron, transmitting an electrical signal that travels through the neuron.

### VESICLES

Sac-like structures at the axon terminal that contain neurotransmitters and release them into the synaptic gap in response to a high enough electrical signal.

### RECEPTORS

Structures on a cell that receive ("catch") molecules and can send a signal into the cell in response. In neurons, receptors trigger an electrical signal that travels through the cell.

## WHAT ARE NEUROTRANSMITTERS?

What exactly are the signals sent between neurons? They are made of chemicals called **neurotransmitters**. Imagine two friends playing a game of catch with a baseball. The "thrower" throws the ball across the lawn to the "catcher." Similarly, imagine two neurons are communicating using neurotransmitters (Figure 2). The "thrower" neuron is called the presynaptic neuron—"pre" means "before" and tells us this neuron is before the synaptic gap. The presynaptic neuron releases the neurotransmitter across the "lawn" (synaptic gap), where it is caught by the "catcher" neuron, called the postsynaptic neuron (meaning "after" the synaptic gap).

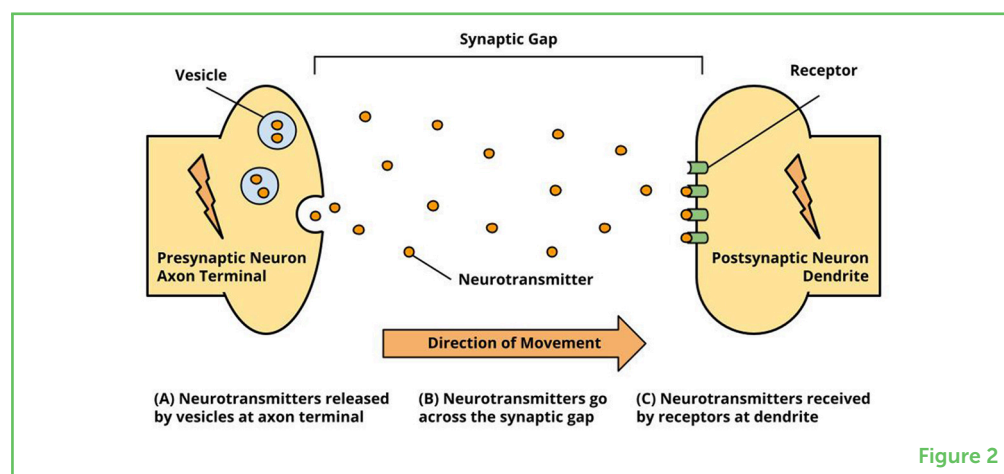


Figure 2

While this is what generally happens, the details are a little more complex. Neurotransmitters are stored in tiny sac-like structures called **vesicles** at the axon terminal. When neurotransmitters travel across the synaptic gap, they bind to molecules called **receptors** on the dendrites of the "catching" neuron—you can think of receptors as the "hands" doing the catching. When enough receptors "catch" the neurotransmitters, an electrical change is created in the receiving neuron, and this charge moves through the cell body and down the axon [2]. When the electrical signal reaches the end of the axon, the vesicles in the axon terminal release their neurotransmitters into the synaptic gap, and they travel across to communicate with even more neurons by the same method. This is the basic method by which the neurotransmitters in your brain influence the emotions you feel.

The three most common neurotransmitters involved in emotions are dopamine, serotonin, and norepinephrine [3] (Figure 3). These three different "balls" control your everyday moods and emotions! A good balance between "throwing" and "catching" each of these neurotransmitters is important to keep you physically and mentally healthy.

**Figure 3**

The three main neurotransmitters associated with emotions are dopamine, serotonin, and norepinephrine. Dopamine is the “reward and pleasure” neurotransmitter. Serotonin is the “satisfaction and self-confidence” neurotransmitter. Norepinephrine is the “attention and reaction to stress” neurotransmitter. Understanding these three neurotransmitters can explain their roles in our everyday emotions and can help doctors treat some psychiatric conditions and other diseases that affect mood.

**PSYCHIATRIC DISORDER**

Health conditions that affect the way a person feels, thinks, and behaves. Examples include schizophrenia and depression.

	General Role	Low Levels	High Levels
Dopamine	Reward Pleasure	Anxiety Parkinson's Depression	Addiction Schizophrenia
Serotonin	Satisfaction Self-Confidence	Guilt/Shame Anger Depression	Serotonin Syndrome
Norepinephrine	Attention Stress-Reaction	Alzheimer's Parkinson's ADHD Depression	Schizophrenia

Figure 3

**DOPAMINE**

Dopamine is a neurotransmitter associated with emotions such as interest, enjoyment, fear, and anger. However, dopamine alone cannot cause these emotions [3]. Dopamine is a special neurotransmitter that works together with other neurotransmitters, such as serotonin and norepinephrine, to form these emotions. Dopamine also works in the brain’s reward system. Dopamine is released from neurons when the brain receives an unexpected reward, like when you receive a surprise gift [4]. However, too much dopamine can be problematic, as it is linked to addiction and a **psychiatric disorder** called schizophrenia. The symptoms of schizophrenia include losing touch with reality, for example seeing or hearing things that are not really there. Scientists know that excessive dopamine and dopamine receptors are one of the causes of schizophrenia, but they are unsure of the exact mechanism [5].

If you are denied an expected reward, like if you find out your favorite show was canceled, dopamine activity is decreased [4]. Low dopamine levels are associated with emotions like surprise, distress, shame, and disgust [3]. Even lower levels are associated with anxiety and Parkinson’s disease, a nervous system disease that causes movement difficulty. Thus, one treatment for such conditions includes a special chemical that helps the body create more dopamine, which reduces symptoms [5].

**SEROTONIN**

Serotonin is a neurotransmitter associated with emotions such as interest, enjoyment, and surprise. It is also related to disgust, as stimulation of serotonin receptors is linked with disliking the taste of a food [3]. The next time you feel disgusted from eating your most

hated dish, you will know it is from the serotonin firing in your brain. Extremely high levels of serotonin in neurons can lead to serotonin toxicity, which involves symptoms such as nervousness, insomnia, nausea, and shaking [6].

Low levels of serotonin are associated with feelings of distress, fear, shame, and anger [3]. The way these low-serotonin emotions are felt also differs by the person. For example, if you are highly sensitive to the emotions of others and you do something wrong, you will probably feel much more guilt and shame than someone who is less sensitive, who is more likely to feel annoyed or even angry in the same situation [7]. Very low levels of serotonin are associated with psychiatric disorders including depression [3]. Some medications can increase the time that serotonin stays in the synaptic gap, which can sometimes treat the symptoms of depression [7].

## NOREPINEPHRINE

Norepinephrine is a neurotransmitter that plays a key role in attention and alertness as well as in the “fight or flight” response. During times of stress or anxiety, norepinephrine is released and binds to receptors throughout the body. This increases heart rate, dilates pupils, slows down digestion, and heightens the senses—a reaction you may have felt at a time when you were nervous or scared [8]. High levels of norepinephrine make you feel active, aroused, and attentive. So, whether you are being chased by a bear in the woods, are extremely focused on taking a test, excited about performing in a competition, or even feeling attracted to your significant other, high levels of norepinephrine are flowing throughout your body.

Both high and low levels of norepinephrine are related to diseases: low levels are related to Alzheimer’s and Parkinson’s diseases, attention-deficit/hyperactivity disorder (ADHD), and depression, while high levels are related to schizophrenia [8]. Now that you know how norepinephrine affects your reactions, you may be able to understand why high norepinephrine levels can explain emotions such as interest, surprise, distress, and anger while low norepinephrine levels explain terror, shame, and disgust [3].

## SO WHAT?

Hopefully you now have a better understanding of how and why you feel the way you feel! Different combinations of serotonin, dopamine, and norepinephrine create our basic emotions. When all three neurotransmitters are at high levels, we can feel interest and excitement, while having all three at low levels can generate feelings of shame and humiliation [3]. Control of feelings, thoughts, and actions is complex and are affected by other factors than the three neurotransmitters discussed in this article. Still, serotonin, dopamine,

and norepinephrine do play a major role in our mood. So, whenever you feel happy, sad or anything in between, remember that these tiny chemicals are at work all over your body to make you feel that way.

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## YOUNG REVIEWERS

### C.R., AGE: 9

I like rock music and playing soccer. Math is my favorite subject at school. I really do not know what else to add.

### JIA, AGE: 15

I enjoy reading, watching shows and learning new things. I find science particularly fascinating due to it being all around us.

## AUTHORS

### AMY KIM

Hello! I am currently an undergraduate student at The University of Texas at Austin, pursuing a Bachelor of Science in biochemistry. After completing my degree, I plan to pursue a career in science. I hope to grow and learn in this field to help and serve others, and to ultimately be a positive influence on all those around me. In my free time, I enjoy singing, crocheting, and watching dramas. I find my faith to be a great source of comfort and motivation.

### PANISARA SUTTHIPONG

I am an undergraduate student at the University of Texas at Austin pursuing a Bachelor of Science in medical laboratory science. I am on the pre-medical track. After graduation, I plan to attend medical school and become a pathologist. My goal is to become more involved in and educate people about the lesser-known aspects of healthcare, such as laboratory work. In my spare time, I enjoy playing the violin in UT's University Orchestra, drawing in my sketchbook, making digital art on my tablet, and playing games with my friends.

### MYA LEVAUGHN

I am an undergraduate student at the University of Texas at Austin pursuing a Bachelor of Science and Arts in neuroscience. After completing my bachelor's degree, I plan to attend medical school in hopes of increasing diversity in healthcare and providing greater comfort for patients from various backgrounds. I love spending my free time hiking, swimming, and painting.





### **NICO OSIER**

I am a principal investigator at the University of Texas at Austin. I have a bachelor's degree in nutritional science and nursing from Michigan State University, and a Ph.D. from the University of Pittsburgh. I am fascinated by the brain and how it impacts people throughout their lives. To learn more about my laboratory, visit my publicly available website: <https://nicoleosier.wixsite.com/osierlaboratory/> or follow @osierlaboratory on Facebook, Twitter, or Instagram. In my free time, I enjoy traveling the world. \*[nicoosier@utexas.edu](mailto:nicoosier@utexas.edu)



## WHAT IS ALZHEIMER'S DISEASE?

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### YOUNG REVIEWERS:



**EMMA**

AGE: 14



**OLIVIA**

AGE: 11

A significant proportion of our aging society suffers from Alzheimer's disease (AD). AD is a disorder that changes the brain tissue and slowly destroys several important parts of the brain responsible for memory, thinking, and communication skills. Over time, patients' forgetfulness increases, and they need more care to carry out even the simplest tasks—such as eating, drinking, or self-hygiene. This can create extremely challenging living conditions for their families. Many children witness how their beloved grandparents or other elderly relatives change, forget things, and eventually do not recognize them or confuse them with their parents. Watching family members progress through the stages of Alzheimer's disease can be a challenging, painful, and even frightening experience for young people. The aim of this article is to explain Alzheimer's disease, its symptoms, and its consequences to help young people understand and cope with this disease if it happens in their families.

## NEURON

A neuron is a special brain cell that acts like a tiny messenger in your brain. It sends messages to other parts of your body, helping you think, move, and feel things.

## NEURODEGENERATIVE DISEASE

A disease that causes brain cells to die and damages the brain.

## CHOLINESTERASE INHIBITOR

A medicine that helps to keep the neuron-communication molecule acetylcholine around a bit longer, to keep messages in the brain flowing smoothly.

## ACETYLCHOLINE

A messenger molecule in the brain, sent between neurons as a form of communication.

## BETA-AMYLOID PROTEIN

A protein that forms toxic clumps around brain neurons.

## TAU PROTEIN

A protein that accumulates inside of neurons, forming toxic clumps called neurofibrillary tangles.

## NEUROFIBRILLARY TANGLES

Clumps of twisted protein fibers that build up inside nerve cells in the brain and disrupt normal brain function.

## WHAT IS ALZHEIMER'S DISEASE?

How do you remember the way to get home? How do you know what the word for chair is? How do you know what day it is? Your brain helps you complete all these tasks. It is what allows you to think thoughts, feel emotions, and learn new things. The brain contains billions of specialized cells called **neurons** that are essential to everything you do. Every time you think a thought or pick up a glass of water, your neurons are communicating with each other.

When someone has a **neurodegenerative disease**, neurons are damaged and can die. This causes miscommunication between neurons, which affects how the brain works. Alzheimer's disease (AD) is a type of neurodegenerative disease [1]. AD is a permanent disease that gradually gets worse over time. One of the first signs of AD is difficulty remembering recent conversations, activities, or events. People may struggle to complete familiar tasks, like turning on the TV, getting dressed, or making a meal. They may get lost easily, forget where they live, or have trouble understanding new information. They may also have changes in mood and behavior, such as becoming anxious or suspicious [2].

AD typically affects people ages 65 or older. Unlike the flu or a cold, AD is not contagious. It is caused by changes in the brain that are still not completely understood by scientists. Around five million people in the USA have AD [3].

There is currently no cure for AD, although there are treatments that can slow down the effects of the disease [1]. Medicines can treat and manage the symptoms of AD, helping patients live their daily lives. **Cholinesterase inhibitors** are one type of medicine used to treat AD [4]. People with AD tend to have lower amounts of a brain chemical called **acetylcholine**. Acetylcholine is a chemical that neurons use to communicate with each other. Cholinesterase inhibitors are used to increase the amount of acetylcholine in the brain, and they can help improve brain function [4].

## HOW DOES ALZHEIMER'S DISEASE AFFECT THE BRAIN?

In the brain of people with AD, there is a buildup of a toxic substance called **beta-amyloid protein**, which forms clumps around neurons [1]. These clumps damage nearby neurons and stop them from communicating with each other. People with AD also have a buildup of another toxic substance called **tau protein**. Unlike beta-amyloid protein, which accumulates around neurons, tau protein accumulates *inside* the neuron cell body. Clumps of tau protein are called **neurofibrillary tangles**, and they can cause cell death and prevent neurons from communicating with each other [3].



Certain areas of the brain are more severely affected by AD than others. The hippocampus and temporal lobe are highly affected areas, and these are the brain regions important in memory. The hippocampus is particularly important for storing long-term memories and converting short-term memories into long-term memories, so that you can remember things that happened to you a long time ago [5]. The hippocampus also helps process events, locations, and times [5]. In AD, neurons in the hippocampus are damaged and eventually die [1, 6]. This can prevent the hippocampus from working properly, leading to memory loss [2]. A person with AD might not be able to recognize family members or might call a family member the wrong name. The person also might not be able to remember where they are or how they got there.

AD can also affect a part of the brain called the amygdala, which is involved in emotions and emotional reactions [5, 6]. Damage to the amygdala in AD is associated with personality changes, mood changes, anxiety, and irritability [7]. A brain area called the frontal lobe can also be damaged in AD, which can lead to difficulty with planning, multitasking, or decision making [7, 8]. Some people may also have trouble with tasks that must be done in a certain order, like cooking [7]. Some AD symptoms are more common than others, but AD can affect people in different ways. Two people with AD might have completely different symptoms.

## WHAT CAUSES ALZHEIMER'S DISEASE?

There is not one thing that causes AD—there are many things that affect whether or not a person gets it [1]. Things that increase the chances that a person will develop a disease like AD are called risk factors (Figure 1). The most significant risk factor for AD is age: the majority of AD cases are in people who are 65 years old or older, and the likelihood of developing AD almost doubles every 5 years past the age of 65 [3]. That means that someone who is 70 years old is almost twice as likely to get AD as someone who is 65 years old, and someone who is 75 is almost four times as likely to develop AD than someone who is 65 years old.

**Genetic mutations**—certain changes in a person's DNA—are another risk factor for AD [1]. Many mutations have been found to be associated with developing AD, but the genetics of AD are complex and are not yet fully understood. Because mutations can be inherited, this also means that a person who has a family member with AD might be more likely to develop AD in the future. But just because a person has AD does not guarantee that their relatives will develop the disease. Other factors such as diet and medical conditions are also important risk factors for developing AD [1].

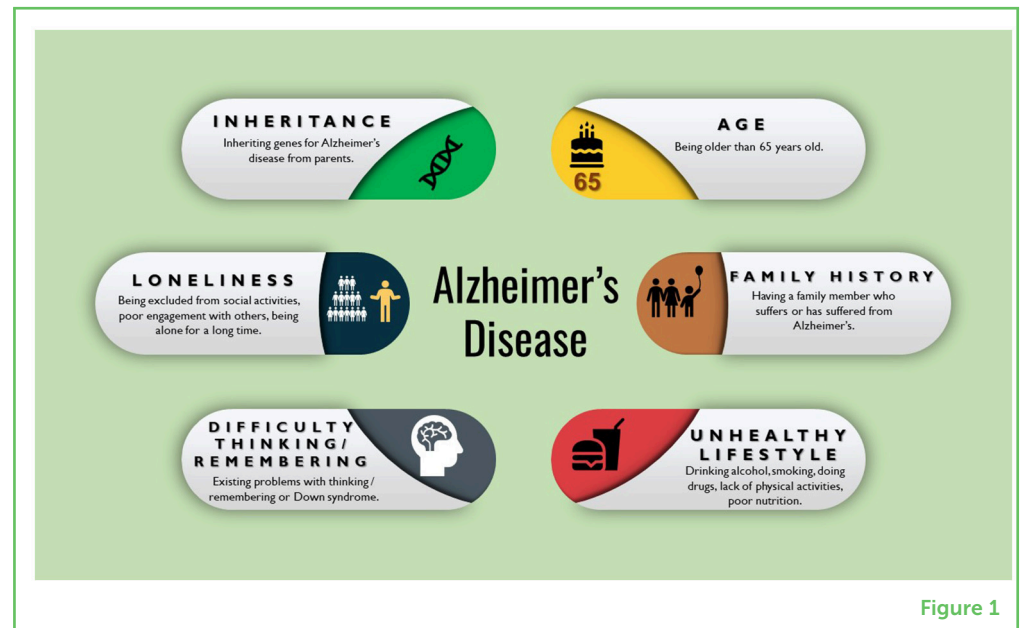
### GENETIC MUTATION

A change in the DNA sequence of a gene that can be good, do nothing, or be harmful.



**Figure 1**

Things that can increase a person's chances of getting a disease like AD are called risk factors. The more risk factors a person has, the more likely the person is to get AD. It is important to note that having these risk factors does not necessarily mean a person *will* develop AD. Rather, risk factors increase the chances of developing the disease.



## WHAT IF YOU KNOW SOMEONE WITH ALZHEIMER'S DISEASE?

If someone you love has Alzheimer's disease, it may be difficult sometimes. The person may not remember events, might call you by the wrong name, or might show personality changes. Your relationship with this person might change as well. It can help to remind yourself that your loved one with AD is still the same person they have always been, even though they may have trouble remembering things or thinking clearly. The person still has feelings, can still enjoy life, and can still experience pain if they are neglected or mistreated. It is important to treat people with AD like any other human being—they deserve to be treated with respect, kindness, and compassion. Even if you feel uncomfortable, weird, sad, nervous, embarrassed, or confused around this person, you can still treat them well. You might feel all—or none—of these things, and that is totally normal.

## HOW CAN YOU SUPPORT SOMEONE WITH AD?

If someone you love has AD, it is important to know that they still care about you. The disease is changing their brain in ways that they cannot control, and that also changes the way that they act. AD is not anyone's fault. There are **several ways** that you can support a loved one with AD (Figure 2):

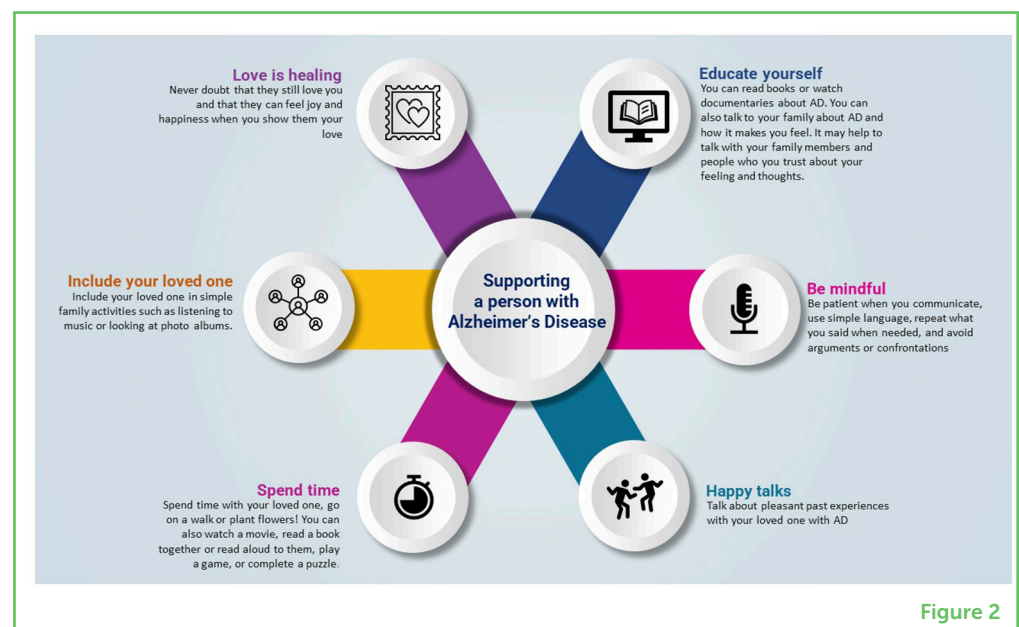
- Love is healing and takes away the pain. Love has a special power that can make things better. If someone in your family has AD, they may have trouble remembering people's faces, names, or where they are. But you should know that, deep down, the person

still loves you just like they always have. When you show the person love and care, it brings them lots of joy and happiness.

- Educate yourself about AD. This knowledge will help you understand what to expect and how to best support your loved one. You can read books or watch documentaries about AD. You can also talk to your family and other people you trust about AD and how it makes you feel.
- Be mindful of how you communicate with a loved one with AD. Talking with a person with AD can be challenging. However, it is very important to be patient, use simple language, repeat what you said when needed, and avoid arguments or confrontations.
- Talk about pleasant past experiences with your loved one with AD. It can help to reminisce about positive things, for example by looking at old photos. You can ask your loved one about their childhood, siblings, school, or pets. It can be uplifting for the person with AD to connect with their past. You can also encourage them to talk about subjects they are interested in.
- Spend time with your loved one with AD. Spending time together shows that you care about them and that they are important to you. You can do something outside, like go on a walk or plant flowers! You can also watch a movie, read a book together or read aloud to them, play a game, or complete a puzzle.
- Include your loved one in simple family activities such as listening to music or looking at photo albums. People with AD still enjoy these types of activities.

**Figure 2**

There are many ways you can provide support to a loved one with AD.



**Figure 2**

If you are spending time with someone with AD, try to be patient with them. On some days they might remember more, and other days their symptoms might be worse. The same is true for any of us: we all have good days and bad days. The most important thing any of us can do if

we have a family member with AD is to remember to support and take care of one another.

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## YOUNG REVIEWERS

### EMMA, AGE: 14

My name is Emma and I am 14 years old. I enjoy reading, my favorite genres are science fiction and adventure and some of my favorite books are What If, The Martian, The Hail Mary Project, Network Effect and A Memory Called Empire. Some of my favorite subjects in school are science, English and theater although I enjoy all of my subjects at school.

### OLIVIA, AGE: 11

Hi, my name is Olivia and I am in 6th grade. I like painting and learning about history. When I grow up I want to be biomedical engineer. I love animals and I have a hamster called Hawk. I also love nature and I have been a Scout since I was a little girl.

## AUTHORS

### SOPHIE HOYER

Sophie is a student at McGill University, Montreal, Canada. Sophie is interested in biochemistry, bioinformatics, and statistics. Sophie is also passionate about science communication and open science. In her free time, Sophie enjoys cooking, being outside, and playing sports!

### STEPHANIE BAKER

Stephanie completed her studies at Boston College in Psychology with a particular focus in Biological Psychology. She is interested in how people can improve their wellbeing by connecting to themselves and their communities. Stephanie served as chair of her local cultural council for years whose mission was to expand access, improve education, and encourage excellence in the arts, humanities, and interpretative sciences. This sparked her love of promoting science education for kids. Stephanie currently works in data analytics at the Boston Symphony Orchestra and in her free time enjoys music, bakeries, running, and gardening.

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Changiz is a full professor and director of behavioral medicine and psychopathology at Oakland University William Beaumont School of Medicine. He received his degrees from Germany. Changiz's teaching portfolio includes behavioral medicine, child and adult psychopathology, brain and behavior, clinical-health psychology, personality psychology, psychological assessment, counseling psychology, and advanced quantitative and qualitative methods. His research focuses on biological, cognitive, and behavioral indicators of resilience, trauma, and emotion regulation. The primary objective of his educational research is to improve students' wellbeing, engagement, success, and learning experiences, sense of inclusion, and retention. \*[mohiyeddini@oakland.edu](mailto:mohiyeddini@oakland.edu)





# WAIT! HOW WE CONTROL OUR THOUGHTS AND ACTIONS AS WE AGE

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## YOUNG REVIEWERS:



AKSHARA

AGE: 13



MAYA

AGE: 15

## INHIBITION

The brain's ability to control unwanted behavior, emotions, and thoughts by stopping them or by preventing them from occurring.

Have you ever sat next to someone in class who cannot stop talking? You would like to focus on your teacher, but you cannot avoid listening to your talkative classmate. This is what inhibition is useful for! Inhibition is the ability to ignore, suppress, and resist irrelevant information coming from the environment or from our own minds. Inhibition is more difficult for young kids, is optimal in young adults, and becomes more problematic as we age. How does inhibition work? Why does inhibition change as we age? Can we train inhibition? In this article, we will try to answer these questions.

## WHAT IS INHIBITION?

Imagine you are in your classroom and want to pay attention to your teacher. In the meantime, you hear two of your friends whispering, and another one is typing on his phone under the table next to you. To focus on your teacher's words, you need to mentally suppress the noise produced by your classmates. This is called **inhibition**. Inhibition



## ACCESS FUNCTION

A function of inhibition that prevents irrelevant information from accessing our awareness, only letting in the important information that we need.

## DELETION FUNCTION

A function of inhibition that removes potentially distracting information that succeeded in accessing the mind, or that removes information that is not important anymore.

## RESTRAINT FUNCTION

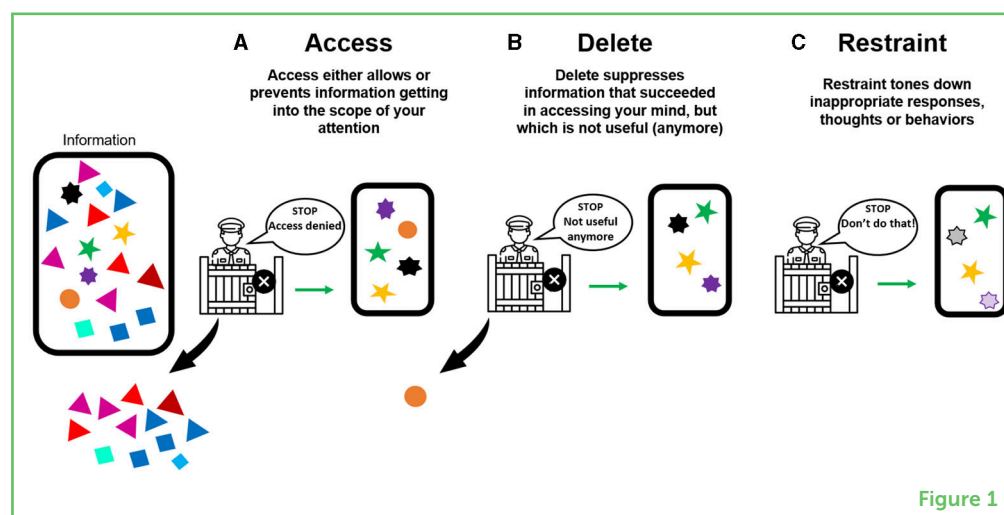
A function of inhibition that reduces strong and inappropriate responses, thoughts, or behaviors.

**Figure 1**

Inhibition has three functions: access, deletion, and restraint. Inhibition acts like a gatekeeper controlling access to an event. **(A)** Initially, the gatekeeper can deny access to the event if a person does not own the ticket to enter. This is the access function of inhibition. **(B)** During the event, the gatekeeper can kick out anyone whose behavior is not appropriate anymore. This illustrates the deletion function. **(C)** The gatekeeper can warn anyone showing excessive behavior during the event. This is the restraint function.

is the ability to ignore, suppress, and resist irrelevant information coming from your environment or from your own mind [1]. It allows you to think, learn, reason, remember, and solve problems without being overwhelmed by too much information. It is also very important for controlling your body and emotions. You can read [this Frontiers for Young Minds article](#) to get more information about how we inhibit physical actions, such as stopping yourself from crossing a road when you hear a truck coming.

In our lab, we are interested in the role of inhibition in memorizing and retrieving information accurately. Inhibition allows us to filter the things we are thinking about or that we are retrieving from memory. This filter has three functions (Figure 1). The first one is the **access function**: inhibition can allow information to reach our awareness or prevent it from reaching our awareness. Access helps us to focus on and memorize the most relevant information while ignoring the many less important bits. The second is the **deletion function**. Deletion removes potentially distracting information that comes into our minds or information that is not important anymore. If you think about a lunch you had last week at school, you would probably remember the friends sitting at your table, and maybe what you ate. But you would probably not remember the color of your chair (unless this information is very important to you). The third function of inhibition is the **restraint function**. Restraint allows us to reduce strong but inappropriate responses, thoughts, or behaviors, such as yelling when you are playing video games if your siblings are asleep.



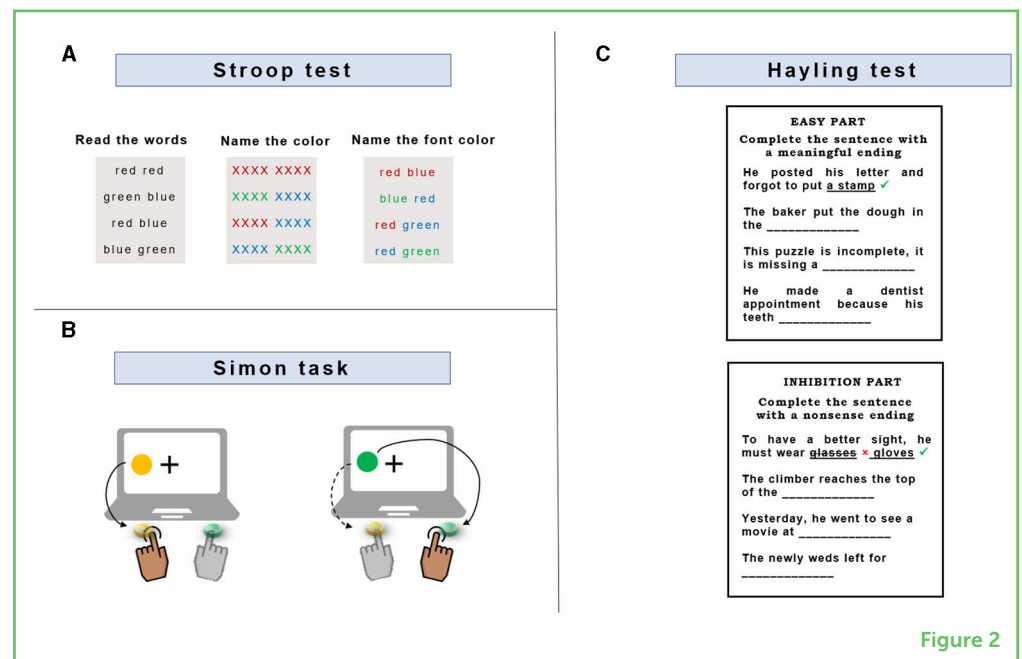
## HOW DO WE MEASURE INHIBITION?

There are many tasks that we use in the lab to measure inhibition. One of them is called the Stroop test (Figure 2A). In this test, people must name the font color of color words, like blue, red, and green. They have to inhibit an automatic response when asked to name the color of the

word. When seeing the word “blue,” the brain automatically reads the word “blue” instead of answering “red.” This is called the Stroop effect. Another task to measure inhibition is called the Simon task (Figure 2B). In this task, people see either a yellow or a green dot on the left or on the right side of the screen. The left button has to be pressed for the yellow dot, and the right button has to be pressed for the green dot. People respond slower and less accurately if the location of the dot on the screen and the location of the response button do not match: that is when the dots appear on right-left locations of the screen opposite to the requested left-right button response; the location on the screen requires inhibition. This is called the Simon effect. The last task we will describe is called a verbal inhibition task (Figure 2C). In this task, people have to complete sentences. In the easy part, sentences have to be completed with a meaningful ending. In the difficult part, sentences have to be completed with a non-sense ending. Participants tend to have difficulties ending sentences with non-sense words if asked to; instead, they want to produce the word that would usually complete the sentence.

**Figure 2**

Several laboratory tests can be used to measure inhibition. (A) In the Stroop test, people have to inhibit an automatic response when asked to name the ink color of the word. (B) In the Simon test, must inhibit the incongruency between the dot and the response button locations. (C) The Hayling test is an example of a verbal inhibition task, in which people must inhibit meaningful endings to complete sentences correctly.



**Figure 2**

## MAGNETIC RESONANCE IMAGING (MRI)

An MRI scanner uses a strong magnet to take pictures of the brain. It helps scientists learn which areas of the brain are active when you engage in different activities.

Another way to study the brain is to look at it using brain imaging techniques, such as **magnetic resonance imaging** (MRI; to learn more about MRI, see [this Frontiers for Young Minds article](#)). MRI studies have shown that, during tasks like the Stroop test that require access inhibition, a part of the brain called the **prefrontal cortex** is extra active. Scientists think that this increased activity might reflect the work of the brain to suppress irrelevant information, allowing us to focus on what is important.

## PREFRONTAL CORTEX

Part of the brain's frontal lobe; the brain area most developed in humans compared to our primate cousins. It supports the regulation of complex mental, emotional, and behavioral functions.

## INFERIOR FRONTAL GYRUS

A region of the prefrontal cortex that is involved in inhibition, language production, and empathetic response among other mechanisms.

### Figure 3

The prefrontal cortex, and specifically a part of it called the inferior frontal gyrus, is the part of the brain that supports inhibition. As people age, the prefrontal cortex gets smaller and a bit less efficient, which can negatively affect inhibition.

## HOW INHIBITION CHANGES WITH AGE

Typically, inhibition emerges around 3–4 years old, becomes more efficient during childhood and adolescence, and is fully developed in early adulthood. But what happens at the other end of human development? As people get older, inhibition tends to decrease, potentially affecting behaviors in everyday life [2]. In the lab, we can compare young adults (18–40) and older adults (60–80) on inhibition tasks like those in Figure 2. Older adults tend to have more difficulties performing these tasks [3]. For example, the Stroop effects can be increased, indicating difficulties with the deletion function. The Simon effect can also be more pronounced, showing a decrease in the restraint function. Finally, older adults may have more difficulties preventing irrelevant information from entering their minds. For example, they may need more time to read a text if irrelevant words are added. This indicates a decrease in the access function. In daily life, problems with inhibition can affect very simple behaviors. For example, we may buy apples instead of pears because we are influenced by the advertisements displayed close to the apples on the supermarket's shelves.

Decreases in inhibition can also interact with age-related decreases in attention or memory. As we explained above, inhibition filters the information that is stored in (and retrieved from) memory. When the filter starts working less well, the wrong information may get selected, and people may also have difficulties rejecting information that was retrieved from memory wrongly.

## WHY DOES INHIBITION BECOME LESS EFFICIENT?

Many researchers have examined the parts of the brain responsible for inhibition in young and older adults. As we already described, using fMRI, researchers have observed that the main part of the brain involved in inhibition is the prefrontal cortex, particularly a part of it called the **inferior frontal gyrus** (Figure 3) [4]. Researchers showed that

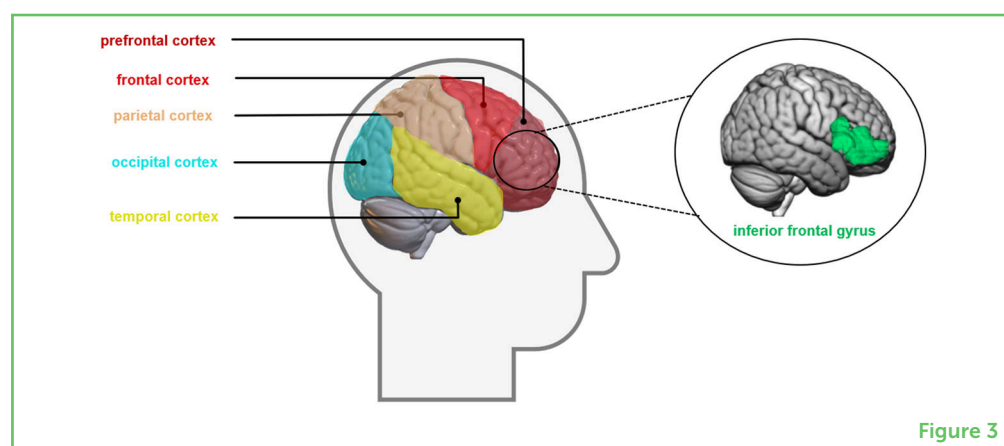


Figure 3

this part of the brain is often underactivated in older adults compared to younger ones, which means that the inferior frontal gyrus works less efficiently as people age. But why? Some studies showed that the prefrontal cortex gets smaller as we get older!

## NOT ALL ASPECTS OF INHIBITION ARE IMPACTED BY AGING!

A recent study compared 11 inhibition tasks (quite similar to those presented in [Figure 2](#)) [5]. Using novel statistical methods, the researchers observed that the decline of inhibition is not the same across the various tasks or functions. For some tasks, there was no difference between the younger and older adults! Other scientists have shown that, even if the prefrontal cortex functions less efficiently in older adults, other brain parts may take the lead and compensate for the reduced efficiency of the prefrontal cortex! The good news is that aging is not an all-or-none process. It involves the recruitment of new brain strategies to cope with the effects of aging that affect some aspects of inhibition more than others.

In summary, inhibition is an essential but also complex ability. This ability shows very strong development during childhood, and then decreases slightly as we age. While the general concept of inhibition is well-studied, future studies are needed to understand the core cognitive and neural processes that define this concept.

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## YOUNG REVIEWERS

### AKSHARA, AGE: 13

Science is everything, from the art of brushing to the way we interact with nature. All the information we learn is gathered in our brain. Our brain is not just a heavy load on our neck, it actually helps us to have fun, dream, and live. I am eager to know more about the mechanisms of how it functions. My aim is to understand how organisms interact with their environment to create a healthy society.

### MAYA, AGE: 15

Maya has an analytical mind and a passion for science. She takes a measured, clearheaded approach to scientific questions and always looks for clarity and evidence in answers. She is particularly interested in the workings of the human mind and what makes people behave the way they do.





## AUTHORS



### COLINE GRÉGOIRE

I am a researcher at the University of Liège and the University of Tours. My goal is to better understand how we control and regulate ourselves. I am particularly interested in evaluating how these processes work as we age. In my free time, I enjoy cooking and having a hot Christmas chocolate at any time, while listening to pop-rock music and petting my two adorable cats. \*[coline.gregoire@uliege.be](mailto:coline.gregoire@uliege.be); [coline.gregoire@univ-tours.fr](mailto:coline.gregoire@univ-tours.fr); [orcid.org/0000-0002-5907-1570](https://orcid.org/0000-0002-5907-1570)



### STEVE MAJERUS

Prof. Steve Majerus investigates the cognitive and neural mechanisms that allow us to hold information temporarily in our mind (short-term memory; working memory). He focuses on the role of attentional control, language in working memory. His research team is also developing assessment and rehabilitation tools for working memory. He is directing the Psychology and Neuroscience of Cognition research unit at the University of Liège. [orcid.org/0000-0002-8206-8097](https://orcid.org/0000-0002-8206-8097)



## RESILIENCE—THE ABILITY TO BOUNCE BACK!

**Jordan Ensz<sup>1</sup>, Melanie Ermler<sup>1</sup>, Huda Rabbani<sup>1</sup>, Madison Saunders<sup>1</sup>, Stephanie Baker<sup>2</sup> and Changiz Mohiyeddini<sup>1\*</sup>**

<sup>1</sup>Oakland University William Beaumont School of Medicine, Rochester, MI, United States

<sup>2</sup>Boston Symphony Orchestra, Boston, MA, United States

### YOUNG REVIEWERS:



**EDDIE**

AGE: 9



**ELLIE**

AGE: 12



**JACK**

AGE: 10



**SAM**

AGE: 11

Resilience means “bouncing back” after a setback, like when you fall off your bike but get back on and try again, or when you do not do well on a test but keep studying and improve next time. This means that when people go through tough situations, resilience helps them to adapt successfully and go back to normal quicker. For kids, resilience can come in handy when you are faced with difficult problems or new environments. Our resilience is shaped by the things we do and the people in our lives. It changes and grows as we experience new things throughout our lives. We can also increase our resilience by building supportive relationships and modeling our behavior after good role models. Resilience in childhood has a big impact on children’s mental, physical, and emotional health and continues to influence them as they grow older. By building resilience, we can improve our grades in school and enjoy life more, while also feeling less worried and sad.

## BOUNCING BACK: THE STORY OF PETER, FATIMA, AND THE POWER OF RESILIENCE

Imagine Peter and Fatima, both kids your age, playing on the school's football team. They lost an important game and, naturally, all the kids felt sad about it. However, their reactions to the loss were different. Peter remained sad for days and did not want to play football for a few weeks. He continued to think about all the mistakes he made during the game, and his sad feelings got worse. He is afraid to play again because he thinks his team will lose once more. On the other hand, Fatima, after feeling a little bit sad, went back to the football field and started practicing again. Fatima reflected on the mistakes she made during the game, and she is determined to improve her football skills.

How can we explain the difference between Peter's and Fatima's reactions to the same **adversity**—the disappointing outcome of their football match? **Psychologists** would say that the key difference between Peter and Fatima is that Fatima has more **resilience**. In this article, we will explain what resilience is, what it does for people, how you can increase your resilience, and the connections between resilience, school performance, and health.

### WHAT IS RESILIENCE?

Psychologists define resilience as a human characteristic or **trait**. Traits are part of who we are as humans, and all humans have the trait of resilience. However, the strength of this trait varies between people—some individuals have more resilience, while others have less.

Resilience helps us deal with tough situations such as losing a football match, receiving a low grade, or coping with our own or a family member's illness. Psychologists often describe resilience as "bouncing back" after experiencing a setback. In other words, when we encounter challenging situations, resilience enables us to adapt successfully and recover more quickly. In the example, Fatima bounced back more quickly than Peter and responded to a difficult situation in a more positive manner, showing more resilience (Figure 1) [1].

Does having strong resilience mean that we should not feel sad when something bad happens? No. When a negative event happens, such as losing something important, anyone can feel defeated, stressed, or sad—it is part of human nature. However, if we have strong resilience, we will feel these negative emotions for a shorter period and find positive ways to cope with them. Remember how Fatima returned to the football field and started practicing to improve her football skills? That is why resilience is crucial for handling **stress** throughout our lives,

#### ADVERSITY

Trouble, hardship, or difficulty.

#### PSYCHOLOGIST

A person who studied psychology and learned to find out how people think, feel, and behave, and helps them with their problems.

#### RESILIENCE

The ability for a person's feelings to return to normal after a challenging or tough experience. Resilience is the ability to bounce back to normal after things go wrong.

#### TRAIT

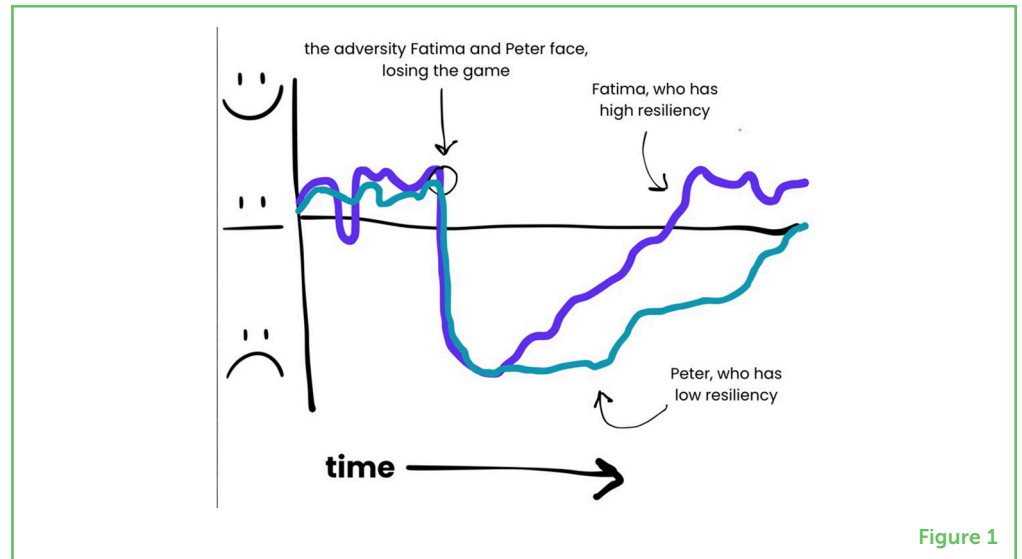
Physical and non-physical characteristics that describe what makes you unique, like creativity or sense of humor.

#### STRESS

The feeling of being worried or nervous about something, like a test, a big game, or a problem with friends. Stress is how your body reacts under pressure.

**Figure 1**

People differ in how much resilience they have. After losing an important football game, Fatima and Peter showed differences in their emotions over time. Fatima has higher resilience and shows a faster return to her normal emotional state than Peter, who has lower resilience, did.

**Figure 1**

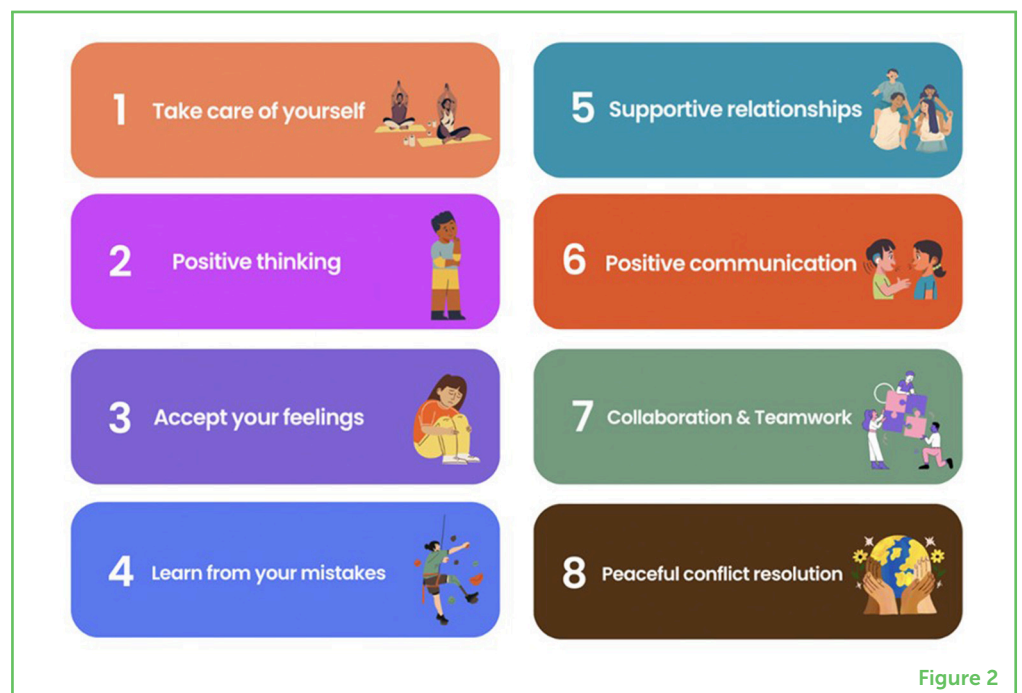
and why it can enhance our school performance, social relationships, quality of life, and health [2].

## WHERE DOES RESILIENCE COME FROM?

Resilience is shaped by how we think, feel, and act, and by the people around us, through a variety of factors that continue to change across our lifetimes [3]. We have the power to increase our resilience by building supportive relationships and modeling our behavior after good role models. Now we will tell you about the things that we can learn and do to improve our resilience (Figure 2).

**Figure 2**

Your level of resilience does not have to stay the same over your entire lifetime—there are things you can do to improve it.

**Figure 2**

**Taking Care of Ourselves**

Resilience means taking care of our physical and emotional wellbeing. Getting enough rest, eating healthy foods, exercising, and doing activities you enjoy can help us feel better after a setback and more prepared to face future challenges.

**Positive Thinking**

Resilient people have positive ways to look at their lives. They focus on the good things and believe in themselves, even when things do not go as planned. They know that setbacks are temporary and that they have the power to overcome them. Positive thinking also helps us to solve problems. When we think positively about problems, we try to solve them and do not hide from them. Problem-solving does not just mean completing math homework—it also means thinking through different options and asking for help if we need it.

**Accepting Our Feelings**

When we lose something important, get bad grades, get sick, or see a loved one in trouble, we feel sad, anxious, or angry. These feelings are not pleasant, but they are not “bad”. We should not deny them or pretend they are not there. Instead, we can redirect these feelings into actions, to change our circumstances for the better. Fatima was sad about losing a football match. However, she used her feelings about the lost game as motivation to practice more.

**Learning From Mistakes**

Mistakes happen, and everyone fails sometimes. By seeing mistakes and failures as opportunities to learn from instead of just feeling bad about them, resilient people try to understand what went wrong and how they can do better next time. They learn from their experiences and become stronger because of them. Fatima tried to learn from her mistakes to become a better football player.

**Positive and Supportive Relationships**

Having friends, family, and other people who care about us and whom we can talk to can make a big difference. When we face challenges, these people can encourage and support us. They can remind us of our strengths and help us find solutions to problems.

**Positive Communication**

Another factor that increases resilience is good communication with other people. Good communication allows us to make connections and create lasting friendships with others who give us support and who can become a safety net when we face hardships.



## Collaboration and Teamwork

When we work in teams and collaborate with other people, we can learn new skills, ideas, and viewpoints. These can be used to help us to deal with challenges.

## Conflict Resolution

Learning how to resolve conflicts peacefully and respectfully can improve resilience. Many conflicts happen because we do not understand each other, not because we want different things. If we take time to explain what we mean and give other people a chance to explain what they mean, we can often resolve conflicts more easily. We could also try to find a compromise or a solution that considers everyone's needs. Using respectful language and active listening skills can help solve the conflict. The more conflicts we resolve peacefully, the stronger our resilience becomes.

## HOW DOES RESILIENCE IMPACT SCHOOL PERFORMANCE?

In one scientific study [4], researchers looked at resilience in a group of children who all faced a similar challenge—they all struggled with reading difficulties. Struggling to read can make school frustrating and affect a child's confidence. In this study, a questionnaire was used to measure children's resiliency, to find out how kids handle tough situations. Teachers rated each child on how well they bounced back after being sick, hurt, or facing other challenges. The study found that children with more resilience had less anxiety and depression, better academic performance, and better quality of life. Interestingly, the researchers also found that the children's overall resilience increased over time [5]. This means that resilience is not a fixed trait; instead, our resilience can grow and get better over time, especially if we work on improving it. Put simply, resilience is like a muscle that gets stronger when we exercise it. So, the more we practice staying positive, learning from our mistakes, and seeking support when needed, the more resilient we become.

### HORMONE

Natural chemicals made by our bodies that are transported through the blood to help our organs communicate with each other.

### CORTISOL

It is a hormone your body makes when you're stressed to help you handle tough situations.

### IMMUNE SYSTEM

The body's natural defense mechanism to fight off sicknesses. It includes the skin, organs, tissues, and white blood cells.

## HOW DOES RESILIENCE IMPACT HEALTH AND WELLBEING?

When we face challenges, we often feel stressed. To deal with stress, the body produces stress **hormones** such as **cortisol**. Stress hormones are very important, and they help us to respond to challenges. But these same hormones also weaken the **immune system**, which protects us against disease. So the more stress we have, the more stress hormones our bodies produce, and the weaker our immune systems become. This can cause us to get sick more often, and it is an important reason why we should learn how to deal with

stress and increase our resilience so our bodies can handle stress more quickly.

## RESILIENCE IN ACTION: PREPARING FOR LIFE'S CHALLENGES

Think back to Peter and Fatima. Who do you think is at bigger risk of getting sick? Peter! Because he was stressed about the lost football match for weeks, his body was more likely to produce stress hormones that can weaken his immune system and increase his chances of illness.

Resilience can be a tricky topic to understand, and even more tricky to apply to real life. But it is important to remember that resilience is not all-or-nothing, and that it can change over time. In your life, you will encounter some challenges that you can easily overcome, and others that take more effort and even some help from other people. The goal should be to reflect on what made certain problems more difficult to bounce back from, and how you can better prepare yourself for the next time. Growing up is full of difficult situations, and practicing how to overcome them can be one of the hardest but most rewarding things you can do to help you handle the challenges you will face moving into adulthood.

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## YOUNG REVIEWERS

### EDDIE, AGE: 9

Eddie loves dancing and making beautiful works of art. She has been homeschooling for 4 years. In her spare time she likes to spend time with her friends and sing karaoke.



### ELLIE, AGE: 12

Ellie is in 6th grade, is a defensive star on her basketball team, and often gets lost in a great book series. She loves to love on her mini goldendoodle and play kickball. She is a self-proclaimed carnivore and enjoys spending time with her family, especially her three little brothers.



### JACK, AGE: 10

Jack is a 4th grader with a curious mind and active body. He loves math and science, plays basketball and soccer. He is often found bouncing around on his pogo stick (no hands!) or playing the piano (both hands!). His origami collection is massive and he cannot stop reading fantasy series while eating grasshopper (mint cookie) ice cream.



### SAM, AGE: 11

Sam enjoys wrestling and CrossFit. He has been homeschooling for 6 years. In his spare time he likes to spend time outdoors with his friends and ride dirtbikes.



## AUTHORS



### JORDAN ENSZ

Jordan is an emergency medicine resident physician who recently graduated from Oakland University William Beaumont School of Medicine. Her research interests during school focused on mental wellness of doctors-in-training, due to how difficult the schooling process can be, as well as the emotional and mental toll working as a doctor can have. Her favorite ways to relax and recharge include hiking, swimming, and hammocking when she is not spending time with her cat named Nugget.



### MELANIE ERMILER

Melanie is a current third year medical student at Oakland University William Beaumont School of Medicine. She is from Michigan and attended the University of Michigan for college, where she studied neuroscience and a minor in German. She has a pet cat named Mona.



### HUDA RABBANI

Huda is a medical student who hopes to help people live healthy lives. When she is not studying, you can find her on an afternoon walk with her friends or stargazing on a clear night with her family.



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Madison is currently a third-year medical student at Oakland University William Beaumont. She went to Central Michigan University where she majored in biochemistry and minored in community health and substance use disorders. She is specifically interested in pursuing a career in emergency medicine or obstetrics/gynecology. When she is not studying for an upcoming exam, she enjoys watching Netflix, cooking, playing board games, and hanging out with her friends and family.



### STEPHANIE BAKER

Stephanie completed her studies at Boston College in psychology, with a particular focus in biological psychology. She is interested in how people can improve their wellbeing by connecting to themselves and their communities. Stephanie served as chair of her local cultural council for years, whose mission was to expand access, improve education, and encourage excellence in the arts, humanities, and interpretative sciences. This sparked her love of promoting science education for kids. Stephanie currently works in data analytics at the Boston Symphony Orchestra and in her free time enjoys music, bakeries, running, and gardening.

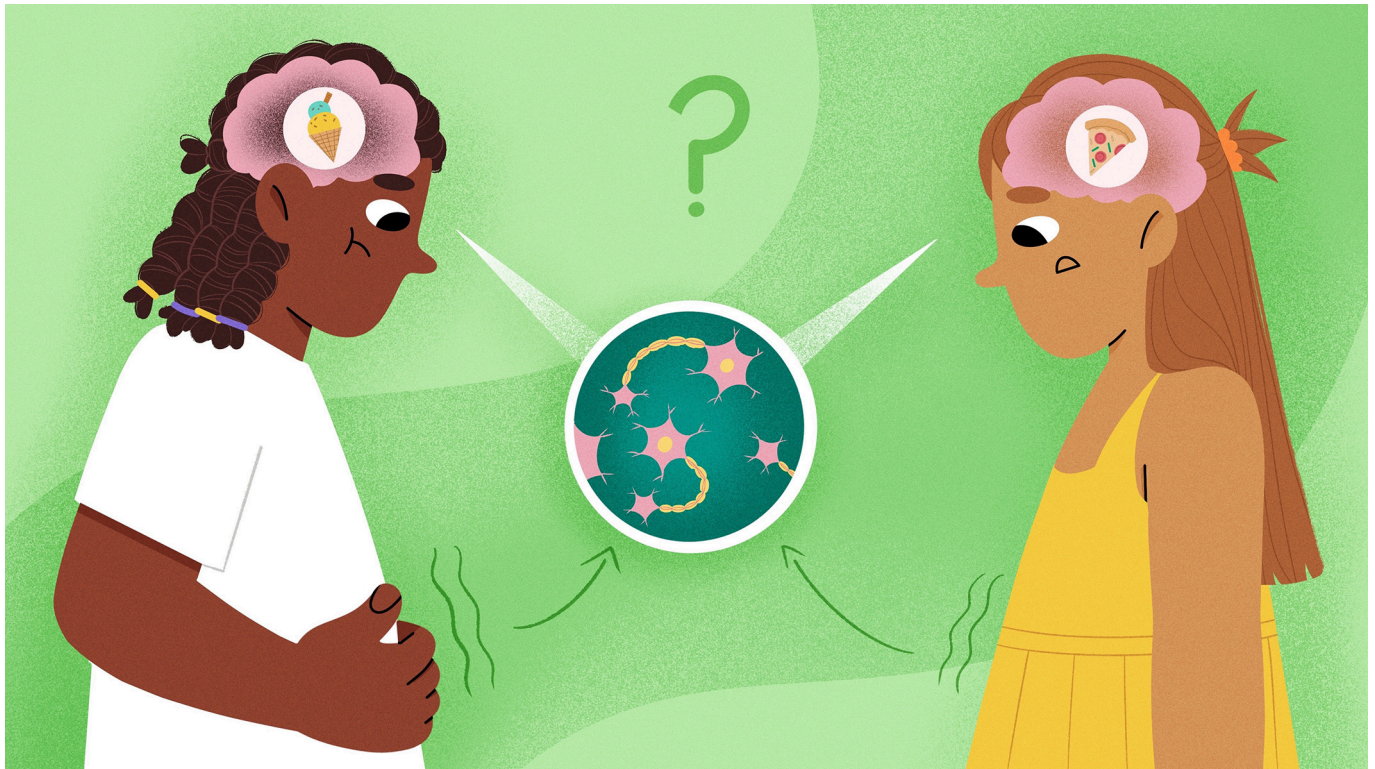


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Changiz is a full professor and director of behavioral medicine and psychopathology at Oakland University William Beaumont School of Medicine. His teaching portfolio includes behavioral medicine, child and adult psychopathology, brain and behavior, clinical-health psychology, personality psychology, psychological assessment, counseling psychology, and advanced quantitative and qualitative methods. His

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# WHAT IS CONSCIOUSNESS AND WHAT IS IT GOOD FOR?

**Inès Mentec<sup>1\*</sup>, Léa Moncoucy<sup>1\*</sup>, Yanis Mouheb<sup>1,2\*</sup> and Axel Cleeremans<sup>1</sup>**

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## YOUNG REVIEWERS:



LEXI

AGE: 12



MISCHA

AGE: 11



NOVA

AGE: 12

What do you see around you right now? What do you hear or smell? How are you feeling—happy, sad, bored? And what thoughts are in your head? All the sensations, feelings, and thoughts you have every day are part of what is called your conscious experience—something that all humans have. But do they have a purpose? Would you act the same without them? These are the questions we will address in this article. We will first introduce the concept of conscious experience and then review the methods that scientists use to study it, which is not an easy task! Finally, we will explain why it is important to study consciousness at all.

## WHAT IS CONSCIOUS EXPERIENCE?

Look at everything surrounding you right now. The computer screen upon which this article is displayed probably stands on a table. On this

## PERCEPTION

The process of using our senses to capture signals and the interpretation of these signals in the brain. For example, our eyes (sensors) capture light (signal) and we see an image (interpretation).

## CONSCIOUS EXPERIENCE

“What it feels like” to experience everything you can experience: emotions, sensations, feelings, and even thoughts. Conscious experience goes away under deep sleep.

## SUBJECTIVE

Designate something that depends on your point of view and can vary from one person to another.

table, there may also be some strawberries you are planning to eat. You can have thoughts about the strawberries and objects you see: you can tell what color they are, and if they are warm or cold, for example. The information you get through your senses is called **perceptions**. Beyond perceptions, you can also feel whether you like each object or not. You could grab a strawberry and feel its sweet juice filling your mouth and be happy about it. Finally, you can remember things that happened in the room you are in, like when you used to play with your dolls, or when you celebrated your birthday there.

Everything that happens in your mind—including perceptions, emotions, thoughts, and memories—make up what is called **conscious experience**. You can be aware of all those pieces of information and feelings at any time, every second of your day. You cannot stop this flow of sensations and thoughts even if you want to—consciousness cannot be turned off. Every moment you are awake, you are experiencing something.

## CONSCIOUS EXPERIENCES ARE FOR YOU, AND YOU ONLY

Conscious experiences are said to be **subjective**. This means that they belong to you and to you alone. No one else can directly feel the sweetness you feel eating a strawberry the way you feel it.

To make this clearer, imagine calling a friend on the phone—someone who has never been in the room you are in right now. You could describe the color, size, and texture of your environment; and you could tell your friend whether you like the room or not. But your friend will never feel exactly the way you feel in this room.

Experiences vary widely from one person to another, and the range is even wider when you consider other living species. You, because you are human, can have a rough idea of what it feels like for another human being to appreciate the taste of a strawberry, but you can have no idea what it feels like [1] for bees to sense the direction of the North Pole, for example.

Yes, honeybees can sense the planet’s poles! (Figure 1). For humans, the direction of the North Pole is information we can access by looking at a compass. But you do not, and probably never will, directly *feel* what it is like to gather that information through one of your senses. You do not need to use a device like a compass to know that a strawberry tastes sweet. In the same way, honeybees do not need a compass to know where the North Pole is, they just feel it.

### Figure 1

Honeybees can sense Earth's poles. It is as though they have a compass inside their bodies that can sense the direction the North Pole is in! This ability helps them to navigate. In addition to honeybees, some kinds of turtles and birds possess similar abilities. Humans will never know what it feels like to sense the North Pole the way honeybees do.

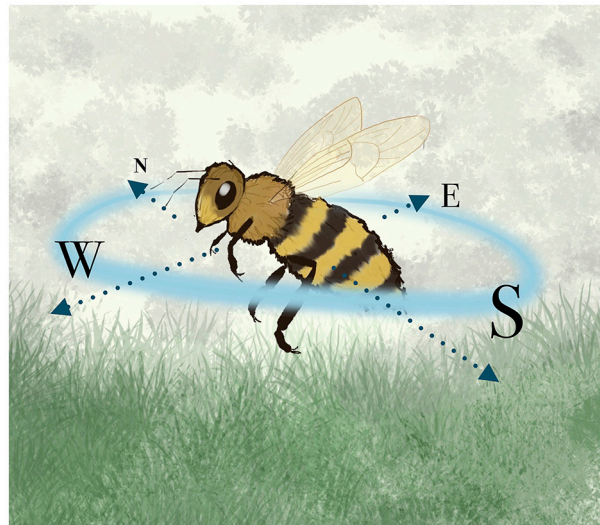


Figure 1

## HOW CAN THERE BE A SCIENCE OF CONSCIOUSNESS?

Knowing that honeybees can feel the direction of the North Pole is completely different from actually feeling it. And we cannot ask the honeybees to tell us what it is like! Now you may wonder: If no one can see, share, describe, or measure conscious experiences, how can scientists study consciousness [2] (Figure 2)?

### Figure 2

Scientists have several ways of studying conscious experience. **(A)** People can report their experiences to scientists. In this example a child is talking about an image of a bunny they saw. **(B)** Scientists can use neuroimaging techniques to take pictures of brain activity, which they can view on a computer. **(C)** A person's body reactions, like heart rate, amount of sweat, and where their eyes are looking, can help scientists understand the person's conscious experience. None of these methods are painful!

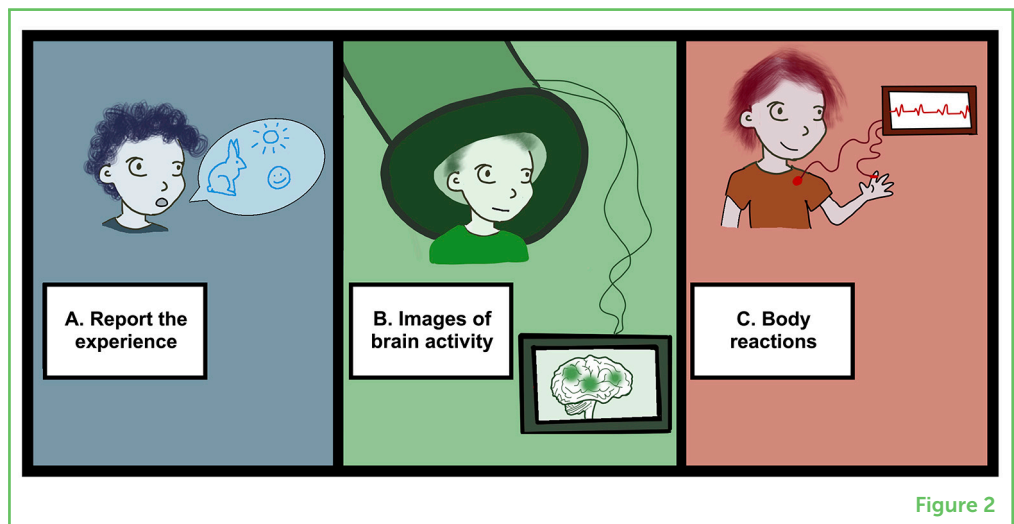


Figure 2

As mentioned earlier, one way for others to know about your experience of eating a strawberry is for you to communicate it with words. You can explain what you feel when you eat it. You can describe its sweetness and the juice filling your mouth. You can report many details about your experience. In this way, scientists can have partial access to what you are experiencing. However, the method of just asking people how they feel does not work on other animals. And it only works for awake human beings who know how to speak, and



## NEUROIMAGING

A set of methods that make it possible for doctors and scientists to visualize brain activity on a computer screen.

who *can* speak. Some mental particularities, illnesses or injuries can indeed make someone unable to speak.

Scientists can also measure the brain activity related to an experience. These techniques are called **neuroimaging** because, using them, scientists literally get images of brain activity on a computer screen. However, there is not always a perfect match between the images scientists get from the brain and the experience itself. For example, scientists cannot tell the difference between the thought of a banana and the thought of a strawberry just from neuroimaging techniques.

Another way to access a person's conscious experience is to look at their bodily reactions. For example, if you are afraid of thunder, your heart will most likely beat faster when the sky lights up: scientists can measure that rhythm. While scientists can never be absolutely sure about what caused the acceleration in your heart rate, they can use a type of math called statistics to gain confidence in their reasoning. Thanks to all these tools, scientists are slowly starting to gain a better understanding of how consciousness works.

## A "HARD PROBLEM" REMAINS

While consciousness scientists have tools to understand how consciousness works, they still must deal with a very difficult problem that will keep them busy for a long time. This problem is: why do we have conscious experiences? This question is so hard to answer that people who study conscious experience actually call it the "Hard Problem of Consciousness" [3]. Let us try to make it a little easier.

The hard problem is hard because it is difficult to imagine what it would be like not to be conscious. We are always conscious, every second of every waking day of our lives. One way to better understand this question is by using your imagination. Imagine a world where there are human beings, like us, and also another kind of beings. Let us call them **Humanatons**. Humanatons look similar to us in every respect. They live their lives the same way we do. They wake up in the morning, eat their breakfast, play with their friends...but these Humanatons do not feel anything. They have no conscious experiences. They would not feel tired, nor the pleasure of tasting their cereal, nor the happiness of being with their friends. They would still function properly, they just would not feel themselves working (Figure 3).

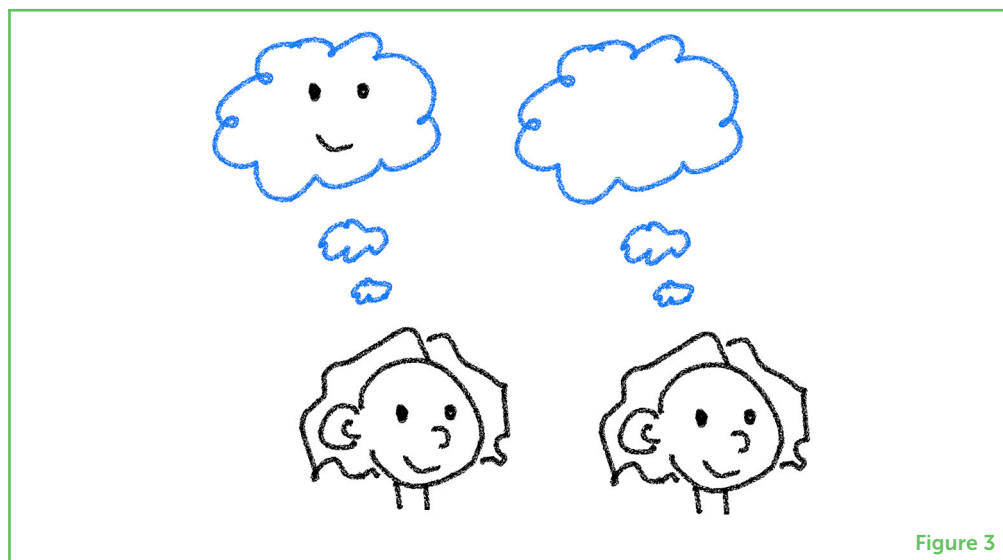
In this imaginary world, the Hard Problem could be phrased this way: in comparison, why do we, human beings, feel ourselves living? Why not live our life like these Humanatons, if they are as good as we are at living their lives without any sensory experiences or any feelings? Do human beings have something more by having a conscious experience, beside the experience itself? Researchers are having trouble answering all these questions.

## HUMANATONS

Imaginary beings that appear and act as humans but lack consciousness. In the field called philosophy of mind, they are known as "zombies"—but are nothing like the ones from Hollywood.

### Figure 3

On the **left**, a human is having a conscious experience of happiness. On the **right**, a completely made up being called a Humanaton is smiling, but it does not feel happy. It does not feel unhappy, either. For example, if a Humanaton pinched its finger in a door, it would cry because Humanatons act like human beings, but it would not feel any pain. This kind of imaginary scenario can help researchers to think about important questions, like why humans have conscious experiences.



## ONE POSSIBLE ANSWER

Scientists currently have several answers to the Hard Problem, but not every specialist agrees on one answer. We will now talk a little bit about our favorite answer: we say that, even in this imaginary world, Humanatons could not exist. Conscious experiences may have a function—they may motivate you [4]. The pleasure you feel eating the strawberry could motivate you to eat it. What would be the point of doing anything if doing it did not make you feel something? Why would you eat the strawberry if it were not for its taste or to stop being hungry? The answer is that you probably would not eat it. Actually, you would not do anything at all without your conscious experience.

To put it another way, the more you enjoy having an experience, the more you will try to replicate it; the less you enjoy it, the more you will try to avoid it. Our lead to the Hard Problem suggests that conscious experiences give us the feeling of having little goals all the time. The reason we do things would be that we feel good when we achieve them, and bad when we do not.

## WHAT GOOD IS CONSCIOUSNESS RESEARCH?

You now know what consciousness is, how researchers study it, and that an unanswered question is “why do we have it?” This research may seem quite pointless to you. Why bother studying something that is both obvious to everyone and very hard to measure?

Well, as you read, a lot of beings cannot talk, and therefore they cannot communicate their needs to us. We then must assume what they feel based on indirect clues only. If a dog wags its tail, we have good reasons to trust that it is happy. But we may be wrong because we do not communicate the same way dogs do.



If a being (whatever it may be) is conscious, then it may be able to feel pain, sadness, or other negative feelings. And no one enjoys feeling pain or sadness. Thus, we should protect conscious beings from these negative feelings. To do so, we can write laws. For instance, it is forbidden to beat pets because we assume that they can feel pain. In comparison, there is no such law preventing us from beating a table. The reason is that we do not think a table is capable of feeling pain. Laws protect beings as long as we think they can feel, which means have a conscious experience. We are on a path toward treating animals differently in terms of their rights as conscious beings. That is a very important goal, and a good reason to want a better understanding of conscious experiences.

## ACKNOWLEDGMENTS

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## YOUNG REVIEWERS

### LEXI, AGE: 12

My name is Lexi and I am 12 years old. I like microbiology, macro photography, and cats. My plan is to become a microbiologist in research.



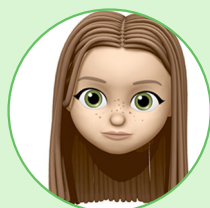
### MISCHA, AGE: 11

Hi everyone! My name is Mischa. I love playing soccer, drawing, listening to music, watching The Simpsons and I also really enjoy reading! At school, my favorite subjects are sport, math, science, English and geography. I live near a beach and I am a "nipper", which means that every summer I practice swimming and paddling on a rescue board in the surf, for the local life saving club.



### NOVA, AGE: 12

Hi, I am Nova! I am twelve and I love astrobiology and philosophy! My favorite book series is Keeper of the Lost Cities by Shannon Messenger, and I am a violinist and singer! I also love writing short stories and I am in the middle of writing a novel!



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### INÈS MENTEC

Inès Mentec is a Ph.D student in the Psychology Department of the Université Libre de Bruxelles. She works on the function of conscious experiences or the question "why do we feel anything?". To do so, she uses behavioral as well as neuroimaging methods and she analyzes her data using powerful computer programs. Her past life as an engineering student really helps her in her research. Outside of the lab she likes to dance and to spend time with her relatives. \*[ines@mentec.ulb.be](mailto:ines@mentec.ulb.be)



### LÉA MONCOUCY

Léa Moncoucy was born in France and is now living in Brussels, Belgium. She is currently a Ph.D. student in psychology, but before that, she did both a master's in cognitive sciences and of philosophy of science. She is mostly interested in research about consciousness, what it is for, how to measure it, and its relationship with feelings. She also loves drawing, martial arts, and science-fiction! \*[lea.moncoucy@ulb.be](mailto:lea.moncoucy@ulb.be)





### **YANIS MOUHEB**

Originally from Paul Sabatier University (Toulouse, France), Yanis is currently finishing his master's thesis at the Centre for Research in Cognition and Neurosciences in Brussels, under the supervision of Axel Cleeremans. He is studying the influence of our beliefs on our body. In the future, he is eager to continue working with Axel, as he wants to pursue the scientific journey that is the study of consciousness and perhaps answer the question: is there something more than that? [\\*yanis.mouheb@univ-tlse3.fr](mailto:yanis.mouheb@univ-tlse3.fr)



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Axel Cleeremans is a research director with the F.R.S-FNRS (Belgium) and a professor of cognitive psychology at the Université Libre de Bruxelles, where he heads the Consciousness, Cognition and Computation (CO3) Group and the Center for Research in Cognition & Neurosciences. His research is dedicated to understanding the differences between conscious and unconscious processing, as well as the how and the why of consciousness itself.



## DO PRIMATES MAKE FRIENDS LIKE HUMANS?

**Anna Ilona Roberts<sup>1,2\*</sup>**

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### YOUNG REVIEWERS:



**DIVYA A.**

AGE: 15



**MIRAL**

AGE: 15



**MOHAMAD**

AGE: 15



**TALIN**

AGE: 15

Have you ever wondered what skills you need to make friends? How your brain processes the information that you need to make friends? What features of your daily life make having friends difficult? Primates are the mammals that are most similar to us in the animal kingdom. Primates face similar challenges to humans when it comes to making friends. Primates must understand the goals and intentions of others to make friends. However, the stress they experience in their environments can make understanding others' goals and intentions difficult. Stress causes primates to switch from understanding goals to understanding behavior alone, meaning they respond only to input from their senses. To overcome this challenge, primates use sounds and gestures when making friends. These are called intentional communication, and they motivate animals to figure out the goals of other animals by using their knowledge of past interactions. Knowing how primates communicate to make friends can help us to understand how humans make friends, too.



## PRIMATES

A group of mammals that include monkeys, apes, and humans, known for their large brains, forward-facing eyes, and ability to grasp objects with their hands.

## VIDEO 1

Bonobo grooming, recorded in the Wamba site.

## AWARENESS

The ability to perceive and understand what is happening around you, including recognizing changes in your environment and reacting to them.

## WHAT IS FRIENDSHIP IN PRIMATES?

**Primates** are the mammals that are most similar to us on the tree of life. Like humans, primates are intelligent and live in large, complex social groups. Primates have friendships within and outside their families—but do primates create friendships the way humans do? It is difficult to identify friendships in animals that do not speak, but we can see friendship in the ways animals interact with one another. Scientists can tell that primates are friends when they remove parasites from each other's fur during grooming, for example [1]. I filmed examples of grooming behavior in a primate species called bonobo (see [this video](#) of bonobo grooming in Wamba). The bonobos I studied live in the Democratic Republic of the Congo in Africa. In the Wamba site, Japanese scientists have been studying bonobos for over 50 years!

## WHY ARE PRIMATE FRIENDSHIPS COMPLEX?

The survival and health of primates depend on their success in complex social interactions. **Awareness** is a key skill necessary for social interactions in primates [1]. Awareness means using the knowledge of a certain situation that is stored in memory. Animals can use awareness to understand the goals of other members of their species. However, not all social interactions involve use of awareness. For example, understanding behavior does not take awareness—it can occur when animals respond to input from their senses that comes from their external environment, such as tactile (received through touch), auditory (received through hearing) and visual (received through seeing it).

## WHAT IS THE DIFFERENCE BETWEEN UNDERSTANDING BEHAVIOR AND UNDERSTANDING GOALS AND INTENTIONS?

Many behaviors guide social interactions without the need to understand each other's goals and intentions. For instance, if your classmate Rosie stamped her foot and then hit you, this experience would shape your reactions the next time you see someone stamp their foot. You would be scared when you saw foot stamping because you would anticipate being hit, even if hitting did not actually happen. This direct experience of the event would guide your future behavior, even if you did not know anything about Rosie's goal in terms of why she stomped her foot and hit you. Sensory inputs such as tactile and auditory displays evoke strong emotions because they are highly predictive of rewarding (positive) or unrewarding (negative) outcomes. In contrast, visual displays are less predictive of outcomes and evoke weak emotions which are neither positive nor negative. If Rosie's



## AMBIGUOUS

Sensory input or situation can be interpreted in two or more distinct ways.

behavior did not actually predict anything, to respond to Rosie you would need to figure out, in *your* mind, the goal that Rosie has in *her* mind.

Understanding goals or intentions is not easy: the goals of others are often **ambiguous**! Ambiguous means there are many solutions possible in a given situation. For instance, when you see Rosie walking toward you across the street, you might wonder: Does she want to talk to me? Or is she waiting for someone? Or does she have a completely different goal?

Predictions about other's goals are often ambiguous because we figure them out from our prior social interactions [1]. Animals behave differently toward different group members depending on how they previously interacted together. They can also change their behavior depending on changes in social interactions between themselves and other group members. For instance, Rosie usually always talks to you, but if you quarreled with Rosie's friend, Rosie might not talk to you for a while.

Predicting others' goals in large social groups is especially complicated. When there are many group members, this requires storage of much information about prior social interactions. Imagine you are at school with 80 children—this means there are more than 3,000 possible pairs of children who can interact with each other every day. The number of combinations of three children is even larger—more than 82,000 different combinations of three children exist in a school of 80 children!

There is a limit to how much information about social partners can be stored. Animals store information about their close social partners better than they store information about others. Usually, animals can only store information for up to five group members. Thus, animals have only a few friendships because they lack information about group members with whom they do not interact often.

When animals do not know goals of others, these social interactions are ambiguous. When animals only understand behavior, in response to ambiguous situations they experience fear and want to avoid one another. When animals can understand the goals of others, this helps them to make friends. To understand the goals of others, they use knowledge of past social interactions. Recall the example of Rosie. We discussed that when you see Rosie crossing the street, you might wonder: Does she want to talk to me? Is she waiting for someone? If you were trying to figure out Rosie's goals, many goal options might be possible. However, you would probably come up with one main goal, by focusing on the most important aspects of the situation such as who Rosie is and your history of interaction. This "zooming in" would help you to respond to Rosie in an appropriate way. Primates may also be able to "zoom in" their attention to figure out the goals of others.

Sometimes, they may come to recognize that the goals of another member of their group are similar to their own goals. This produces a feeling of “liking” the other and wanting to be friends [2].

## INTENTIONAL COMMUNICATION HELPS PRIMATES UNDERSTAND GOALS AND INTENTIONS

Like humans, primates use movements of their bodies and hands (gestures) to communicate with each other [3]. They also communicate by making sounds with their vocal tracts [4]. These signals are considered **intentional communication** when the signaler looks at the recipient prior to or after signaling. Intentional communication motivates primates to use their knowledge to understand the goals of others [2, 4, 5]. Watch [this video](#) to see an example of this communication in the bonobo.

In [this video](#), 18-year-old adult female Puffy is being groomed by a young female named Zeta. At first, Puffy is not looking at Zeta. At this point, Puffy does not find grooming Zeta to be important to her own goals. As she grooms Puffy, Zeta looks at Puffy and touches her gently on the sides of her back with both of her hands. Soon, Puffy turns around and starts grooming Zeta intently. This tells us that Puffy now realizes that she and Zeta have the same goal: Zeta being groomed by Puffy. However, Puffy lacks any evidence in the surrounding environment that this is actually the case! Touching with both hands does not convey the message that Zeta wants to be groomed by Puffy. Touching with both hands occurs in many situations. It only motivates Puffy to try to understand Zeta’s goal. Puffy only knows Zeta’s goal because she zoomed in on Zeta’s goal using knowledge of other situations in the past. Without this knowledge, Zeta’s touching with both hands would not help Puffy work out Zeta’s goal.

Communication signals like Zeta touching Puffy with both hands are called **attention getters** [3]. Attention getters are distinctive signals such as making sounds with objects, touching gently, or attracting attention by making hand gestures.

Now watch [this video](#) for an example of intentional communication in the chimpanzee.

The old male chimpanzee Maani is scratching. He is next to a young male chimpanzee, Bwoba, who is lying on the ground. Bwoba shows the inner part of his arm to Maani while looking at him. Maani starts grooming Bwoba. This raising of the arm motivated Maani to figure out Bwoba’s goal. As this situation repeated itself over time, Maani worked out Bwoba’s goals—in response to the arm-raising gesture, Maani might sometimes recall one social interaction more often than others. This happened simultaneously with Maani becoming friends

### INTENTIONAL COMMUNICATION

When an animal deliberately sends a signal to influence another animal.

### VIDEO 2

Intentional communication in the bonobo—a focal follow of bonobo Puffy, recorded in the Wamba Research Camp.

### ATTENTION GETTERS

Actions or signals used to capture the attention of others, often to communicate or influence group dynamics, like gentle touches or manual gestures.

### VIDEO 3

Intentional communication in the chimpanzee—a focal follow of chimpanzee Bwoba, recorded in the Budongo Conservation Field Station.

## INTENTION MOVEMENTS

Signals which help recipient infer goal of signaller.

## ACUTE STRESS

A short-term reaction to an immediate threat or challenge, causing a quick burst of energy and alertness.

## CHRONIC STRESS

A long-term state of constant tension and worry, often resulting from ongoing pressures or problems.

with Bwoba. When signals such as raising of the arm cause the watcher to choose one goal of the signaler over other goals, they are called **intention movements**. Bodily postures and visual hand signals, which are shared signals between the signaler and the watcher, are common types of intention movements.

## WHY DOES STRESS MAKE FRIENDSHIPS DIFFICULT FOR PRIMATES?

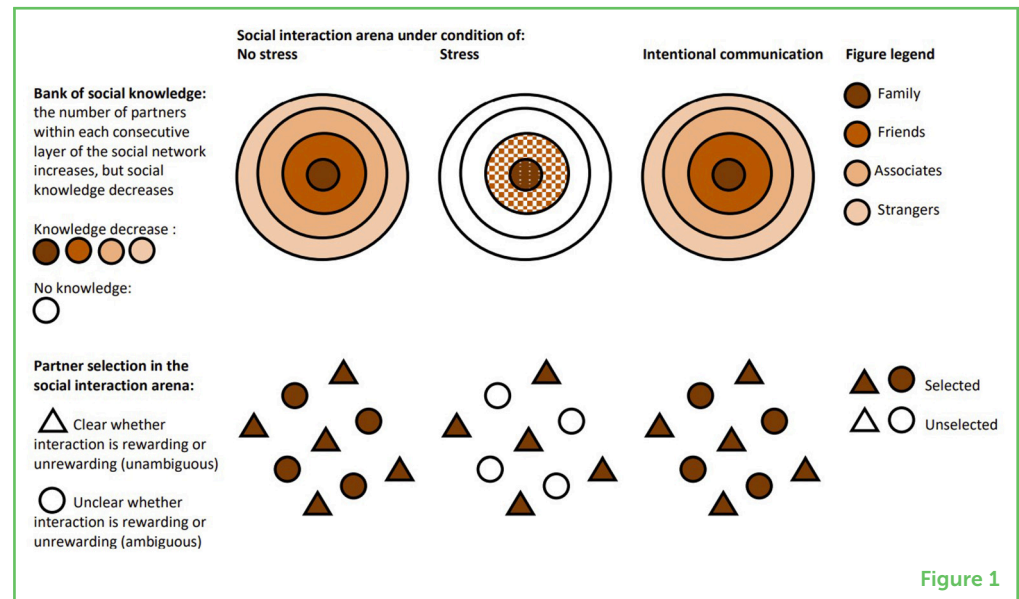
**Acute stress** often involves the drive to defend oneself against sources of danger (predators, aggression) and to prevent being alone or hungry. Stress helps animals to get the resources they need (social partners, shelter, food). Initially animals zoom in on dangerous situations—but also on neutral, ambiguous situations. However, stressful situations compete with neutral, ambiguous situations for limited memory resources. This happens until success is impossible forcing animals to “zoom in” their attention on unambiguous, stressful situations and “zoom out” of ambiguous, neutral situations when zooming in would benefit them. When animals “zoom out”, they are not focused enough to work out the goals of their social partners, so the social interactions are more ambiguous. As animals zoom out, ambiguous interactions including ambiguous sensory input (e.g. visual) evoke negative emotion and fear. When animals zoom out long term this is **chronic stress**.

## HOW DOES COMMUNICATION HELP PRIMATES OVERCOME STRESS AND MAKE FRIENDS?

Some primates, such as chimpanzees, have evolved to understand intentions in order to make friends because stress makes having friends difficult [6]. During stress behavioral information coming through the senses does not match up with signaler’s goal or intention. Researchers studied whether intentional communication helps chimpanzees to make friends during stress by helping them to understand intentions (Figure 1). Intention movements helped chimpanzees to make friends when they were acutely stressed. These stressed chimpanzees remembered one main goal of social interaction with their friends. This happened when sensory input alone did not make them approach to be friends. When chimpanzees were chronically stressed and they used attention getters, they were able to make friends. Chimpanzees used attention getters with the partners that they did not know well. Chimpanzees figured out the goal of the other to make friends, when neither direct experience with that partner nor sensory input were enough to allow them to approach the partner to be friends [6].

**Figure 1**

Hypothesis for Communicative Roots of Complex Sociality and Cognition [2] explains the link between social and communicative complexity. Sources of stress deplete “bank of social knowledge”. Social partners from outer layers of the social network, who are competing for selection in the “social interaction arena” are not selected. During acute stress animals bias attention toward unambiguous interactions, either positive or negative. Zooming out of ambiguous interactions long term causes chronic stress. Intentional communication motivates animals to use their knowledge. Animals deploy bank of knowledge to understand ambiguous interactions with social partners from the outer layers, therefore these partners are also selected. This expands the number of partners with whom animals interact and makes “social interaction arena” more diverse and complex.



## CONCLUSION

When humans first met primates in the jungle, we were amazed. We asked: are primates like us? At first, people thought that primates were not like humans because people believed that primates only understood behavior. People claimed that humans were unique in understanding the goals and intentions of others. But the similarity in communication and social dynamics between primates and humans suggests otherwise. Communication strategies that primates use suggest that primates are very much like us. Stress causes problems with processing of social information, just like in humans. This reduces the number of social partners with whom primates come into contact. Communication strategies, such as attention getters and intention movements, allow primates to broaden the range of social partners with whom they interact [2]. Primates can thrive in the complex social groups in which they live, similar to the way humans do. The complex communications and social interactions of our ancestors help to explain why we have language today: we evolved large brains and language to make friends in large, complex societies [1].

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## YOUNG REVIEWERS

### DIVYA A., AGE: 15

I am a sophomore in High School and I am passionate about neuroscience and healthcare. I have completed a research project examining variations in autism spectrum disorders presentation and severity through the lens of genetics/biology as well as healthcare systems (e.g. diagnosis, treatments, etc.).





**MIRAL, AGE: 15**

I am 15 years old. I am looking forward to be a doctor in the future since I have a great interest in biology. My favorite thing to do in my free time is playing sports or making pastries.

**MOHAMAD, AGE: 15**

I am 15 years old. I am interested in both biology and physics, I speak three languages, and one of my favorite things to do is riding horses, reading, and traveling, I am also interested in medicine.

**TALIN, AGE: 15**

I am 15 years old. I am absolutely captivated by the fascinating worlds of biology and psychology. I love exploring articles about the intricate workings of life, from the tiniest cells to the complexities of the human brain, science always has me hooked. As a young reviewer, I am thrilled to help make science in these areas exciting and easy to understand for young people who share the same interests as me.

## **AUTHORS**

**ANNA ILONA ROBERTS**

In my work I have ample opportunities to understand why friendships make primates similar to humans. I met Indigenous people in the jungle of Brazil who would pick lice from each other's hair and eat it to make friends. I also saw grooming behavior between bonobos at Wamba, Democratic Republic of the Congo, and chimpanzees in Budongo, Uganda. I studied chimpanzees and bonobos and observed how their hand gestures are so similar to those that humans use. I also observed that, like humans, these primates use hand gestures to engage in social interactions. These experiences made me conclude that primates are not that different from humans! \*[ar2295@cam.ac.uk](mailto:ar2295@cam.ac.uk)



## PARENTAL “SUPERPOWERS”: HOW CAREGIVING CAN SHAPE KIDS’ DNA

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### YOUNG REVIEWERS:



**HENRY**

AGE: 13



**JANE**

AGE: 13



**JINYI**

AGE: 9

Every day, parents take care of children and by doing so they promote their children’s emotional wellbeing and the way their brains work. Are you curious about how such parenting “superpowers” work? It turns out that tiny chemical tags on people’s DNA, known as epigenetic markers, play a big role. These markers act like switches, turning genes on or off, and they can be influenced by people’s experiences. In this article, we focus on the effects of parents’ nurturing behavior on kids’ epigenetic markers, which can pass messages from the environment (the parenting kids receive) to kids’ genes, influencing gene function. Understanding how these markers work can help people understand why they feel certain emotions and behave in specific ways. Through this article, we aim to inspire curiosity and understanding in young minds about the fascinating interplay between experiences, genes, and emotions.

## DNA

A molecule in most cells that contains instructions for building the body and keeping it functioning.

## GENES

Sections of DNA that are each responsible for a specific characteristic or function.

## PROTEINS

Molecules produced from genes, which are used by the body for many purposes, including building tissues, sending signals, speeding up reactions, and defending against illnesses.

## GENE EXPRESSION

The cellular process of turning genes into proteins.

## EPIGENETICS

The study of changes in gene activity that do not change the DNA sequence but are caused by chemical markers, affecting how genes are turned on or off.

## EPIGENETIC MARKERS

Molecules linked to DNA that can cause some genes to be more or less expressed.

# WELCOME TO THE GENETIC ORCHESTRA

Welcome to the fascinating realm of **DNA** (aka Deoxyribonucleic acid), the small molecule in each of our cells where the secrets of life are encoded. How did scientists unravel the mysteries of this extraordinary molecule? Let us journey back to the mid-20th century when a team of brilliant minds (James Watson, Francis Crick, Rosalind Franklin, and many others) unlocked the enigma of DNA. Their groundbreaking discoveries have revealed the true nature of DNA, not like any molecule, but as the very essence of existence.

DNA contains vital information on how each part of our bodies should work. Every specific piece of information is contained in portions of the DNA called **genes**. Genes are made of a series of smaller units called nucleotides. There are four unique nucleotides: adenine (A), thymine (T), cytosine (C) and guanine (G), which are ordered in unique sequences in every gene. Each gene can be used as instructions to prepare one of the many **proteins** that the body uses for most of its functions. The cellular process of turning genes into proteins is called **gene expression**. If you like music, you can think of the nucleotides as the notes on the staff. Similar to how sequences of nucleotides make up different genes, musical notes can be combined to create different melodies. Thus, DNA is like a collection of different melodies that can be played together like an orchestra score, creating a functioning human body.

Although all cells contain the same DNA, not all genes need to be “turned on” in every cell all of the time. Differences in gene expression are what give cells their unique functions. Genes can be used to create proteins or left unused. This can be thought of like a musical score that is played in different ways by the orchestra, silencing or highlighting various melodies. Interestingly, science has revealed that things in the world around us can impact our DNA, turning genes on or off.

# REGULATING THE “MUSICAL SCORE” OF DNA

So, if DNA is not just a static musical score, how can it be “played” in different ways? Gene expression can be influenced by chemical changes to the DNA called **epigenetic** mechanisms [1]. But how does it work? Epigenetic mechanisms can change the structure of DNA, turning genes on or off, like a switch. For example, adding a small group of carbon and hydrogen molecules (called a methyl group) to the DNA changes the shape of the molecule and basically “blocks” nearby genes from being turned into proteins. So, depending on their placement, methyl groups and other **epigenetic markers** can cause some genes to be more expressed, producing more proteins, and others to be less expressed, producing less proteins (Read more on epigenetics [here](#)). Epigenetic mechanisms are like the conductor of

the orchestra, telling each instrument when and how to play its melody and transforming the musical score into a dynamic symphony.

Here is the really interesting part: while our DNA remains the same throughout our lives, the genes that are expressed can vary based on things in our surrounding physical and social worlds. The information that comes from our environments (for example, how our parents take care of us) and other experiences we have can leave their mark on our “genetic melody”, shaping who we are and who we will become. It is through the interplay between genetics and epigenetics what makes each one of us unique.

## WHAT MAKES A GOOD RAT MAMA?

Our work started with a question that might sound rather strange at first: What makes a good rat mama? In the enchanting world of rats, rat mothers use special behaviors when they take care of their offspring. Imagine a rat mama gently licking her young ones, grooming them with tender care, and arching her back to nurse them affectionately—a set of caregiving behaviors called licking, grooming and arched-back nursing (LG-ABN). These behaviors weave a cocoon of love and warmth around the babies.

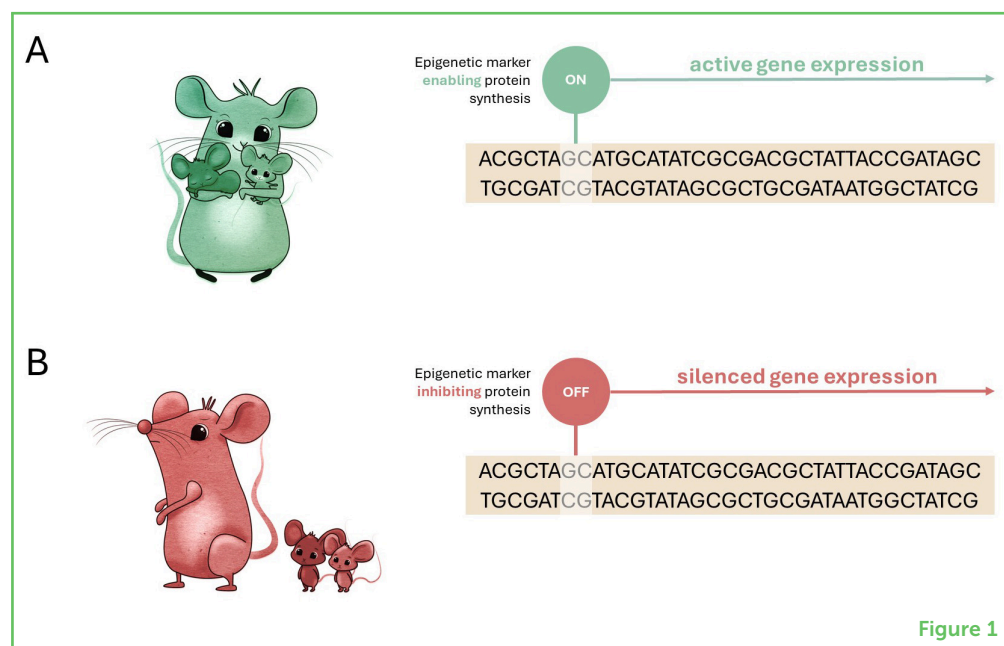
About 30 years ago, Canadian scientists embarked on an adventure to understand the power of rat mamas’ behaviors [2]. Specifically, they wondered whether the way a rat mama takes care of her babies could leave a special mark on the pups’ DNA. To study this, they observed rat mamas that showed different levels of LG-ABN behaviors. Some mothers were very loving, showering their babies with lots of care. Others were a bit more reserved, giving their babies less attention.

They discovered that the pups of the very loving rat mamas, who received lots of care and affectionate touch, had a specific set of epigenetic markers on their DNA. In particular, genes related to stress management had epigenetic markers that helped them produce more proteins. In rats whose mothers were more reserved, these same genes had epigenetic markers that led to the production of less of those proteins (Figure 1). This finding indicates that rats who had caring mothers may have an easier time dealing with any stressful situations they experience in their own lives, while rats raised by reserved mothers may have more trouble coping with or recovering from stress. Overall, these results showed that the way a rat mama takes care of her little ones can leave a lasting impression on their DNA. It is as if her love and tenderness sculpted the way her babies could respond to stressful situations and manage the ups and downs of life. But does this also apply to humans?



## Figure 1

Variations in caregiving behaviors in rats can change the epigenetic markers in their offsprings' DNA. **(A)** The genes of pups raised by mothers who display nurturing caregiving behaviors can be expressed and produce proteins. **(B)** In pups raised by mothers who display less nurturing caregiving behaviors, the same genes may have epigenetic markers that turn the genes off, resulting in less protein production from those genes.



## PARENTAL CARE IS AN EPIGENETIC “SUPERPOWER”

Scientists have uncovered a similar connection between caregiving and epigenetics in humans. Imagine a parent’s touch, a warm hug, or a gentle caress acting as a protective “shield”, nurturing their child’s development from the inside out. Just like the loving grooming and nurturing behaviors of rat mamas, human caregiving behaviors, especially **social touch**, leave a lasting imprint on a child’s DNA [3]. When parents shower their children with love, affection, and care, they induce a cascade of epigenetic changes activating the expression of protective genes. As in rats, some of the proteins made from these activated genes improve the way the body responds to stressful situations. Thus, parental care can result in an epigenetic “shield” that can protect children from the storms of life, helping them to navigate any rough times they face as they grow up. But the power of parental care does not stop here! Some epigenetic changes caused by caring parents support the development of the child’s brain, nurturing their potential and helping them reach for the stars [4].

Such parental “superpowers” are even more important when infants face greater challenges, such as babies born earlier than expected who need special care in the hospital before they can go home. In such cases there is an extra ingredient needed: skin-to-skin contact. Studies have shown that the loving embrace called “kangaroo care”, in which babies are held skin-to-skin against a parent’s chest, can have powerful epigenetic effects, promoting healthy development and enhancing the ability to bounce back from stress [5].

## SOCIAL TOUCH

Physical contact between individuals that has an affectionate and nurturing meaning.



## LOVING PARENTS, HEALTHY KIDS

As our journey through the world of epigenetics comes to an end, let us reflect on what we have learned. Like a music score, our DNA holds the information needed for our existence. Epigenetics adds dynamic and adaptable features to this “music”. Parents wield a remarkable “superpower”: the power of caregiving. Through loving interactions with their children, parents can help their kids successfully navigate and recover from challenging times in their lives. Tender caregiving behaviors like social touch and skin-to-skin contact allow parents to imprint their children’s DNA with the echoes of love and affection. These epigenetic markers can regulate gene expression and activate a “shield” that protects their children from life’s storms and empowers them to thrive in the face of adversity. In cities, countries, and cultures around the world, parents have the power to release their full epigenetic potential and to help shape and the development of their infants and children, making each one of us different and special.

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## YOUNG REVIEWERS

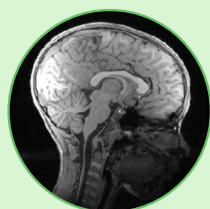
### HENRY, AGE: 13

I love to draw and write, and I actually made and self-published my own book! I love climbing and reading, also. Some of my favorite book series are "Arc of a Scythe" and "Spy School".



### JANE, AGE: 13

I love to learn and work on interesting projects. I enjoy writing fantasy stories, being outside, and spending time with friends. I love working with animals and hope to become a zookeeper one day.



### JINYI, AGE: 9

I am Jinyi, and I am nine and a half years old. I love doing crafts, and lately, I have gotten into using AI to make presentations that bring my ideas to life. I hope to make more friends along the way!



## AUTHORS

### LIVIO PROVENZI

Livio Provenzi is a vanilla nerd, an academic professor of developmental psychobiology at the University of Pavia (Italy) and a researcher with a keen interest in how early interactions between infants and their social and physical environments shape human development. He loves exploring new ways to understand the complexity of child development and is convinced that the secret to child wellbeing lies within caregiver-infant interactions. He feels lucky as his job allows him to travel extensively and explore different cultures... and cuisines. When not conducting



research, he enjoys immersing himself in nerd pop culture and playing the piano.  
\*[livio.provenzi@unipv.it](mailto:livio.provenzi@unipv.it)



### **CAMILLA DE SANTIS**

Camilla De Santis is a master's student in clinical psychology and cognitive experimental neuroscience at the University of Pavia (Italy). She is looking forward to starting a PhD focused on developmental neuroscience. Her mantra is: "Millions saw an apple fall, but only one wondered why". She believes that this one person is like a small child who wonders about the whys of the world. In the end, scientific research and children have much more in common than you might think.



### **ELENA CAPELLI**

Elena Capelli is a speech-language therapist and psychologist currently pursuing a PhD in developmental neuroscience at the University of Pavia (Italy). Her research passion lies in investigating the underlying neural mechanisms, as well as the social and environmental factors, that shape early communication development in children. She is also fascinated by innovative methods of data analysis and the power that a beautifully crafted graph can have in telling stories from mere numbers.



## “PLASTIC” CONNECTIONS BETWEEN NEURONS HELP US LEARN AND REMEMBER

**Chiara Di Fazio<sup>1,2\*</sup>, Elena Protopapa<sup>3</sup> and Sara Palermo<sup>1,4,5</sup>**

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### 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.

## HEBBIAN PLASTICITY

A type of synaptic plasticity where simultaneous activation of neurons strengthens the synapse, encapsulated by the phrase “cells that 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.

## 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,



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.

### 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.

## CHANGING HEBBIAN PLASTICITY FROM OUTSIDE THE SKULL

**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

## 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.

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.

## 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

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.

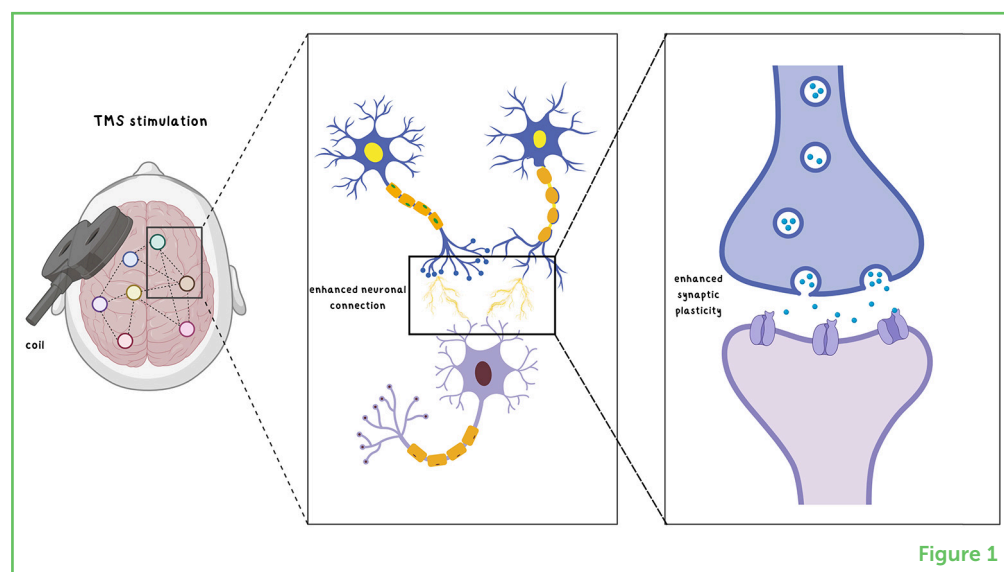


Figure 1

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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## 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

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