

TIME TRAVEL IN THE BRAIN

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Do you believe in time travel? Every time we remember something from the past or imagine something that will happen in the future, we engage in mental time travel. Scientists discovered that, whether we mentally travel back into the past or forward into the future, some of the same brain regions are activated. One of those regions is the hippocampus, a brain structure famous for its role in building long-term memories. Damage to the hippocampus causes memory problems, but it also impairs the ability to imagine future experiences. This brain connection between remembering the past and thinking about the future suggests that memory, planning, and decision-making may be deeply related. The ability to form memories allows us to reminisce about the past. But maybe the ability to form memories also evolved to allow us to think about and plan for the future.

Let us start with a riddle. Try to figure out how to throw a ping-pong ball so that it will go a short distance, come to a dead stop, and then reverse its direction. You cannot throw the ball such that it will curve back to you (like a frisbee), and the ball is not allowed to touch

Figure 1

The hippocampus in human and rat brains. The hippocampus is a seahorse-shaped brain region located in the medial temporal lobe and known for its role in creating long-lasting memories. Images edited with permission from www.nobelprize.org, ©Mattias Karlén/The Nobel Committee for Physiology or Medicine, Karolinska Institute. The original version can be seen on www.nobelprize.org, <https://www.nobelprize.org/prizes/medicine/2014/press-release/>.

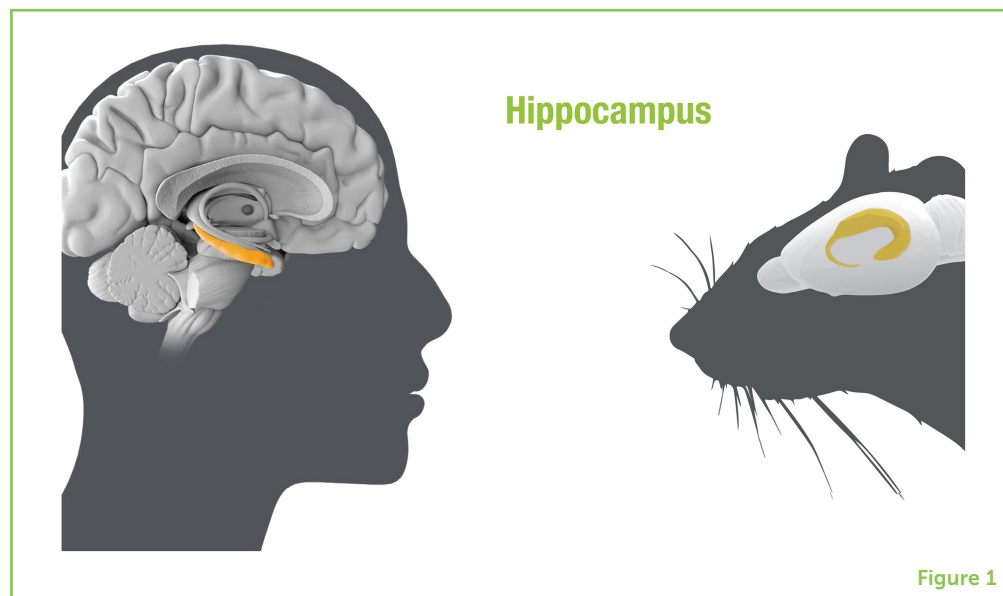


Figure 1

or be attached to any object [1]. What can you do? The solution to this riddle is described in the footnote below¹. Yes, it is a simple solution. Do not worry if you did not figure it out immediately, many people do not. The interesting question is why. Some have argued that people have difficulty solving this riddle because the scenarios we are able to imagine are limited by our past experiences in the world. We are used to seeing ping-pong balls moving around horizontally. So, when we see the ball in our mind's eye, it is hard to envision it moving vertically toward the sky, because we simply have not witnessed many ping-pong balls flying up and down. In this article, we will describe scientific evidence for the relationship between memory and imagination and we will discuss why this relationship plays a role in many aspects of our behavior and, specifically, in how we make decisions.

PATIENTS WHO CANNOT REMEMBER THE PAST CANNOT IMAGINE THE FUTURE

Scientists have discovered that imagining new experiences and thinking about the future involve many of the same brain regions that support our ability to remember the past [2, 3]. One of these regions is the **hippocampus**, a seahorse-shaped brain structure located deep in the brain's medial temporal lobe (roughly behind your ears; see Figure 1; hippocampus means seahorse in Latin). The hippocampus is known to be critical in creating long-lasting memories of events, but it does not work alone. In the healthy brain, the hippocampus works together with other brain areas to allow the storage and retrieval of long-term memories. Patients with damage to the hippocampus often suffer from a condition called **anterograde amnesia** (amnesia means forgetting, and anterograde means in a forward manner): they tend to forget events that happened to them after their brains were

HIPPOCAMPUS

A brain structure located in the medial temporal lobe.

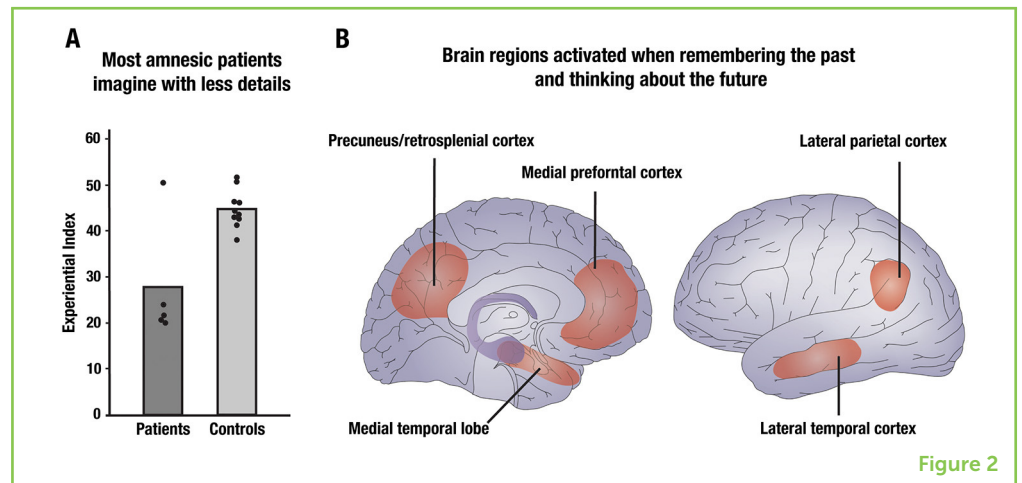
ANTEROGRADE AMNESIA

Loss of the ability to create new memories after the event that caused the amnesia.

¹ You can throw the ball upwards. Gravity will do the rest.

Figure 2

Brain regions important for remembering the past are also active when imagining the future. **(A)** Most patients with damage to the hippocampus describe imagined events with less detail compared with healthy individuals. Note that the single patient who does a good job also has some remaining hippocampus tissue that might help him. Experiential index is a composite score that measures the overall richness of the imagined experience. **(B)** fMRI studies with healthy individuals found a core network of brain regions that plays a role in both memory of the past and thinking about the future. Panel A was adapted with permission from Hassabis et al. [4], Copyright (2007) National Academy of Sciences, U.S.A. Panel B was adapted with permission from Schacter et al. [3], Nature Reviews Neuroscience, Copyright (2007).



damaged, while they can generally remember events that happened before the brain damage. Interestingly, many amnesic patients also have difficulty imagining events in the future [2, 4]. For example, when one amnesic patient was asked to describe what he would do tomorrow, he did not know what to say. He reported that when he tried to think about the future, he felt “blankness” or “like being asleep” [5]. A few years ago, a group of scientists from the United Kingdom tested whether a functional hippocampus is necessary for imagination [4]. They asked several amnesic patients to imagine and describe 10 possible scenarios, like lying on the beach or standing in the main hall of a museum. The researchers counted the number of details that patients included in their descriptions and compared this number to that of a group of healthy people without hippocampal damage. The results were fascinating: whereas the healthy group described imaginary events quite vividly, the amnesic patients could barely do so and produced far fewer details (see Figure 2A). These findings suggest that damage to the hippocampus not only impairs memory, but also impairs imagination.

NETWORK OF BRAIN REGIONS ACTIVE WHEN REMEMBERING THE PAST AND IMAGINING THE FUTURE

Does the hippocampus also contribute to imagination in healthy individuals? Another group of scientists used a technique called **functional magnetic resonance imaging (fMRI)** to test this question [6]. fMRI is used to measure activity in specific brain regions during a mental task. Researchers used fMRI to measure brain activity in a group of healthy individuals while they either recalled a past event (for example, their birthday last year) or imagined a future event they had never experienced before (for example, a trip to France next year). The scientists found that descriptions of these past and future events included a similar number of details, and thinking about these two events also activated a similar network of brain regions, especially the

FUNCTIONAL MAGNETIC RESONANCE IMAGING (fMRI)

A technique used to measure activity in specific brain regions during a mental task.

hippocampus. These findings suggest that the hippocampus works with other brain areas both to enable us to remember the past and to imagine the future (see Figure 2B).

RATS USE PAST MEMORIES TO MAKE FUTURE DECISIONS

The studies described above were all conducted on humans. Other researchers pursue the same questions by testing different species of animals. Animal research enables scientists to measure the electrical activity of individual brain cells (called **neurons**) with electrodes inserted into the brain. Studying rats, for example, led to the discovery that certain neurons in the rat hippocampus, which we call “**place cells**,” play a role in the rats’ memory of specific locations. Scientists recorded the pattern of activity of these place cells as the rats moved around in a maze and again later when the rats were finished exploring the maze. They found that some of the activity patterns measured in the place cells repeated themselves later, when the rats were resting or sleeping. This finding was described as a “**replay**” of those location memories. It looked as if the neurons were practicing the earlier maze navigation.

Interestingly, it was discovered that these memories are also reactivated when a rat has to figure out how to get to a certain place in the maze. In one study, rats were placed in a maze where they could get a reward (for example, food or juice) either on the left or the right arm of the maze. Rats had to decide whether to turn left or right upon hearing a tone that indicated where the reward was located. As in the previous experiments, the scientists started out by recording the pattern of neural activity in the hippocampus when the rats freely moved around, noting which place cells were active in each location of the maze. With this information at hand, the scientists discovered that when the rats faced a decision about which way to turn, neurons in the hippocampus “replayed” the activity patterns associated with turning left and then right, as if the brain was evaluating both options before making a decision. These findings suggest that the hippocampus recalls past experiences to help evaluate future options [7].

THE ROLE OF MEMORY IS TO INFORM FUTURE ACTIONS

You can see from these studies that our memories of previous experiences play a major role when we think about the future and make decisions. Maybe we evolved to have memories not only so we can dwell on the past, but also to help us to predict the future and to make better decisions in the present.

NEURON

A type of brain cell.

PLACE CELLS

Specific neurons in the hippocampus that represent location in space.

REPLAY

Reactivation of patterns of neural activity, typically found during sleep or rest.

Many scientists now believe that the hippocampus has a role in linking together different parts of an experience as well as different related experiences. When you remember your first day in school, you probably think about the appearance of the school, the people who were around, how you felt, etc. These fragments of experience are bound together to create the whole memory with the help of your hippocampus. In a similar way, when you imagine your first day at college, you can remember and put together pieces of your past experiences to create a new image in your mind of a situation you have not yet experienced. This mental ability to travel into the past and future is especially useful when making decisions. By remembering past experiences or by combining memories to form new situations in our minds, the hippocampus (with the help of other brain regions) can provide potential options for the brain to try out. Just like rats navigating a maze, we too can use our memories to make better decisions. When you are at a crossroads, whether having to decide which party to go to, or which high-school to attend, you can imagine each choice, and this mental simulation can help you evaluate how it would feel and how each option might help you to achieve whatever goals you have.

SUMMARY

When we think about memory, we usually think about the past. Indeed, for more than a century, memory researchers focused on how people and animals store and recall past experiences and which brain structures support those functions. More recent research suggests a different view of memory. Recent findings show that the hippocampus—a brain region responsible for memory—is active when people imagine future events. Additionally, in patients with amnesia, damage to the hippocampus impairs the ability to imagine the future. Moreover, when rats navigate their environments, neurons in the hippocampus “simulate” future paths that will enable them to get to a desired outcome. Together, these findings suggest that the hippocampus and its connections to other brain regions build upon past experiences to make predictions about future events. Long before these scientific discoveries, Winston Churchill, the prime minister of the United Kingdom, also seemed to believe that collective memories dictate the future experiences of a people, saying, “a nation that forgets its past has no future.”

AUTHOR CONTRIBUTIONS

NB and DS conceived and wrote the manuscript.

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The Explora Young Minds reviewers are a group of science enthusiasts working with museum educators and mentors from the University of New Mexico. We enjoy learning about the brain through the articles. We also enjoy asking questions and making suggestions to help the scientists make their work more understandable for everyone! We were helped by our Science Mentor Jennifer Walter. She just received her Ph.D. in pediatric neuropsychology. She enjoys working with kids, playing with her dog, and trying to cook new recipes.

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I am a Ph.D. student at Columbia University. I study how memory affects the way we make decisions and how making decisions affects our memory. I am fascinated by our ability to travel in our minds to new experiences, using our memories to help us. I would like to figure out the benefits and consequences of this mental journey: what stays in our minds even if it was not actually experienced and how does this mental travel help us navigate our lives? *natalie.biderman@columbia.edu

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I am a professor at Columbia University, in New York City. My research aims to understand how we learn from experience, how we build memories, and how we make decisions. I have always been curious about why people behave the way they do, and even as a kid I was intrigued by the idea that our behaviors have a biological basis. We are constantly learning from our experiences. What we learn reflects who we are and also shapes who we become. *ds2619@columbia.edu