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YOUR BRAIN'S "SAVE" BUTTON: THE AMYGDALA

Krista L. Wahlstrom* and Cory S. Inman

Immersive Neuromodulation and Neuroimaging Laboratory, Department of Psychology, University of Utah, Salt Lake City, UT, United States

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Do you ever wonder why you remember some experiences better than others? Why do you remember that funny joke your friend told at lunch a few months ago or the scary snake you saw in your backyard, but not that time you went to the post office with your parents? Just like a computer has a save button, our brains do, too! When something scary, exciting, or strange happens, a small part of the brain, the amygdala, helps us click "save" on that event so we can remember it later. Decades of research have helped scientists understand what parts of the brain are important for memory and how the amygdala works with other brain regions to tag experiences as worth remembering. This research is important for understanding how memories are formed and can help us create new therapies for people with memory problems, who have trouble forming new memories and remembering past experiences.

INTRODUCTION

You go to school every day, but you probably remember some school days better than others. What makes 1 day more memorable, and how does your brain save that experience to be remembered for a long time? Much like a computer has a "save" button for when we want to store a picture or a movie, our brains do, too! Although we usually forget most of our daily experiences, if something funny, scary, or strange happens, our brains have a way of "clicking save" on that event so we can remember it later. This ability is essential for remembering important things that happen in our lives that might influence how we act in the future.

Many parts of the brain are important for memory, but the amygdala is at the center of the saving process. When something eventful happens, the amygdala functions as a sort of alarm system that tags the highly emotional experience as worth remembering [1, 2]. Regardless of what happened or where it happened, when the amygdala is highly active after an event, you are more likely to form a strong, long-lasting memory. However, these memories are not like making a video recording of the experience. It is more like a recording that was chopped up into the sounds, smells, feelings, and sights you experienced during the event. Later, when you are reminded of the experience, your brain puts these chopped-up details back together into a story that feels like a video you can remember or share with someone else (and when you cannot remember certain details, your brain fills in the gaps with what might have happened!). The amygdala makes it more likely you will later remember those sounds, smells, feelings, and sights when you experience them.

THE "SAVE" BUTTON

HIPPOCAMPUS

A seahorse-shaped part of the brain that is important for activating other brain regions during memory retrieval, to help put the pieces back together so you can remember.

The amygdala is one small but influential part of a larger network of brain areas involved in learning and memory. When the amygdala gets activated, it tells a neighboring part of the brain, the **hippocampus**, to make note of the many brain regions that were activated by that experience. All those pieces of the memory can be saved and put back together later, when you remember the event. This is like recording a small snapshot of a virtual class for school (Figure 1). The virtual meeting is underway, and your teacher starts talking about something really important, like a lesson about the brain, that you know you will want to remember later. You hit the big red "record" button on the screen. As the meeting continues, you can see the other kids in your class in their video bubbles on the side of your screen. You can also see students typing questions into the chat box while your teacher talks. Occasionally, a student will use the thumbs-up reaction emoji to let the teacher know they understand what is going on. You stop the recording after a few minutes, and it gets saved to a folder on your computer that contains each piece of the recording. The video, the audio, the chat thread, the emojis, and the list of participants, each get saved as individual files to this folder. This is similar to the way the hippocampus stores each part of an experience, so you can remember it later. You can think of the amygdala as important for telling the brain *when* to save an experience, and the hippocampus as the part that is important for knowing *where* the memory is saved and how to stitch these details back together when recalling the memory later. Without this amygdala "save" feature, your virtual class meeting would be lost or forgotten. But hitting the "record" button tells your hippocampus and the rest of your brain to make a memory for the specific pieces of that class experience.

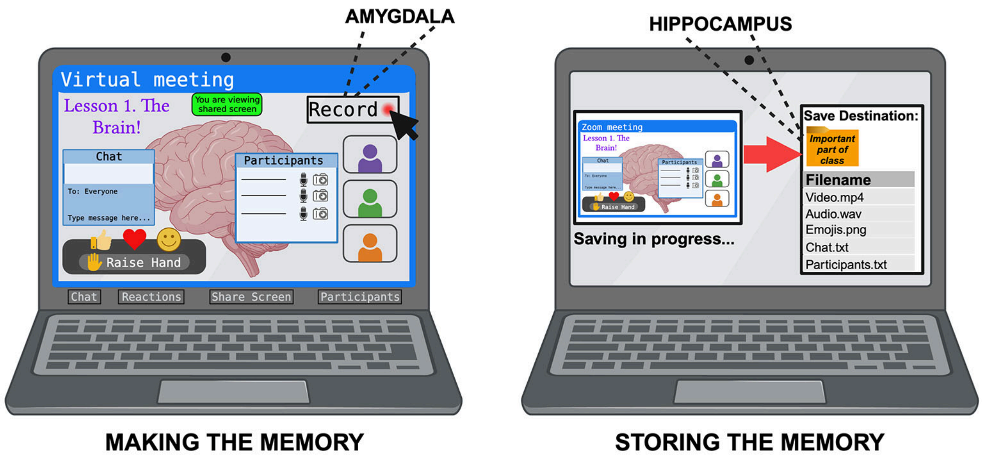

Figure 1

Figure 1

The amygdala is like the "save" feature of a virtual class meeting. Clicking the "record" button saves everything happening during the class, like the lesson your teacher was showing, the conversations in chat, the list of participants, and the audio and video recordings. Each part of the recording is saved to a folder on your computer, so you can watch again in the future. The hippocampus acts like this folder—it stores all the pieces of an experience. The amygdala tells the brain *when* to save an experience, and the hippocampus tells the brain *where* all the components of that experience are stored (created with BioRender.com).

ACTIVATING THE AMYGDALA

The almond-shaped amygdala is a brain region deep behind the ears, near the middle of the brain. Part of the amygdala, called the basolateral amygdala, gets activated during emotional experiences. When something exciting happens, like getting surprised by your friends for your birthday, the **adrenal glands** on top of your kidneys release a substance called **epinephrine**, also known as adrenaline (Figure 2). The adrenaline then causes another part of the brain, the locus coeruleus, to release *another* substance, **norepinephrine**, directly into your basolateral amygdala, causing it to be activated [3]. The activation of your amygdala by this rush of norepinephrine clicks "save" on this experience, making it more likely you will remember this birthday party for a long time.

ADRENAL GLANDS

Small, hat-shaped organs that sit on top of each kidney and release a hormone, called epinephrine, when something scary or exciting happens.

EPINEPHRINE

Also known as adrenaline, this hormone is released by the adrenal glands and is part of the body's quick response to danger, excitement, fear, and even stress.

DISCOVERING THE BRAIN'S "SAVE" BUTTON

Rat brains and human brains have many of the same brain regions and similar connections between those brain regions. This similarity makes rats a great model for figuring out how the brain works. For example,

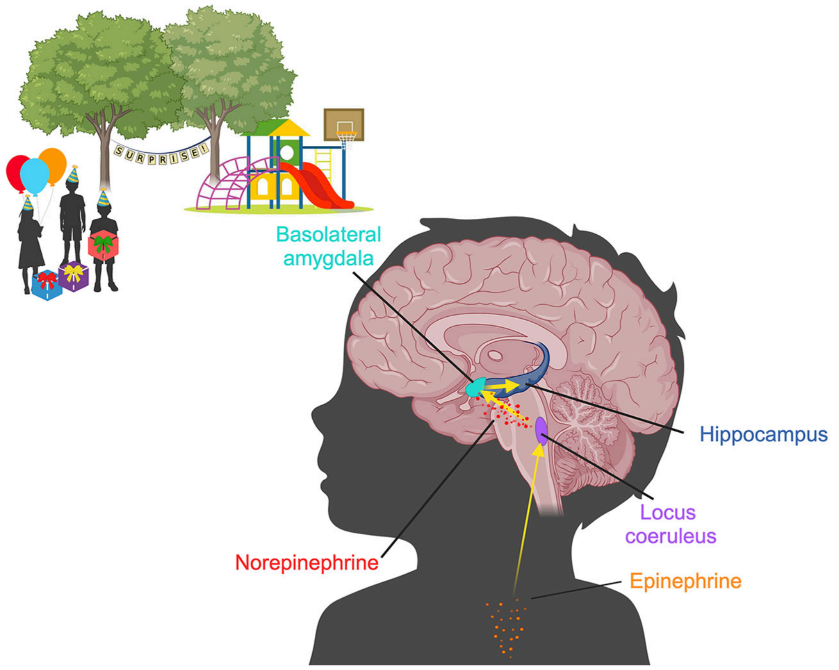

Figure 2

Figure 2

When something exciting happens, like getting surprised by your friends for your birthday, the adrenal glands on top of your kidneys release epinephrine. Epinephrine activates a region in your brain called the locus coeruleus, which then releases another substance, norepinephrine, directly into your basolateral amygdala, causing it to be activated. All of this allows you to remember your birthday and the other things that were happening around you at the time of the party (created with BioRender.com).

NOREPINEPHRINE

A chemical released by a brain region called the locus coeruleus and that activates the amygdala during emotional experiences to help create memories.

scientists know the amygdala is important for saving your memories based on decades of research using artificial ways of activating the amygdala in the rat brain. In some experiments, researchers showed that injecting norepinephrine into a rat's basolateral amygdala caused the rat to better remember the layout of a room, so it could navigate better in the future [4]. Similarly, when scientists surgically placed metal electrodes into a rat's amygdala, applying a tiny amount of electrical stimulation to those electrodes improved the rat's memory for the objects it previously sniffed and saw [5]. Sometimes humans who have seizures also have electrodes implanted into their brains to figure out why they are having seizures. Researchers found that low levels of electrical stimulation of the basolateral amygdala in these patients (about 1/1,000th the strength of a flashlight) increases memory for pictures the people were shown on a computer screen (Figure 3) [6]. This suggests that, by artificially pressing the "save" button in both rodents and people, we can make the brain more likely to remember experiences.

Researchers can also learn a lot about the function of a particular brain region by preventing that region from working. For example, rats given an injection of a drug that stops norepinephrine from activating the amygdala had a difficult time remembering a prior encounter they had with a set of objects [7]. These studies highlight the importance of the amygdala in saving memories, and suggest that, without this brain region, experiences are less likely to be remembered for very long.

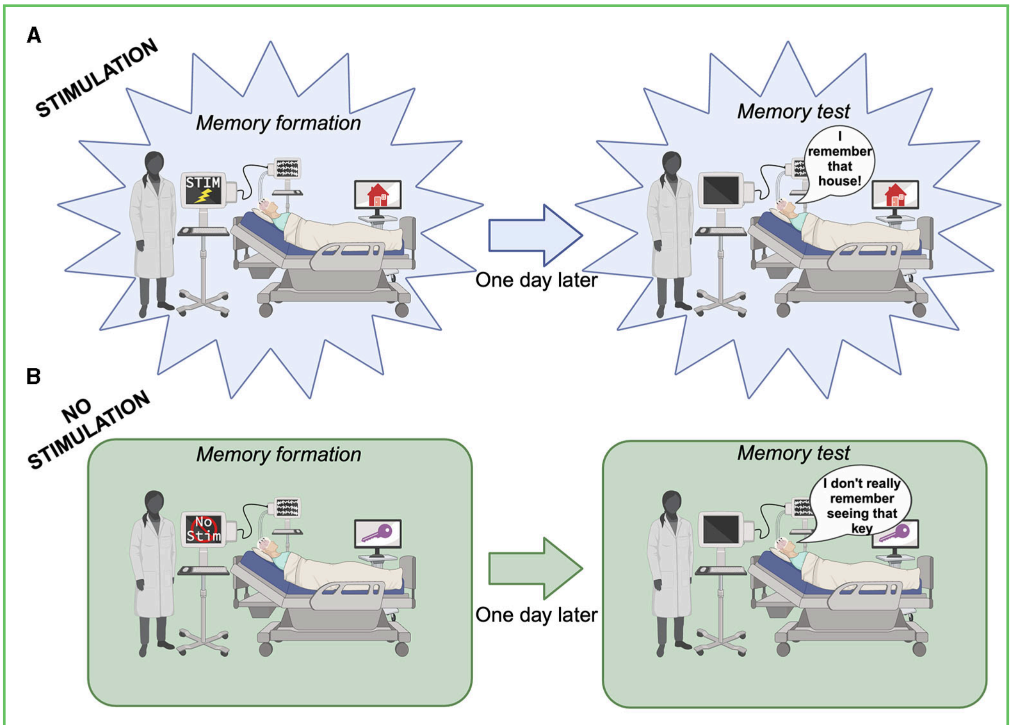

Figure 3

Figure 3

(A) In human patients who have electrodes implanted into their brains (to control seizures), a low amount of electrical stimulation to the amygdala immediately after the person sees a picture on a computer screen (at the time when a memory is being made) causes them to remember that picture better the next day, during a memory test. **(B)** Pictures that are not paired with amygdala stimulation during the time a memory is being made are not remembered as well the next day during the memory test (created with BioRender.com).

SAVE VS. STORAGE

Turning down the activity in the amygdala can worsen memory, and turning up activity in the amygdala can improve memory. However, researchers do not think this is because memories are *stored* in the amygdala. Instead, the amygdala is known as a modulator or influencer of memory because it affects a variety of other brain regions that handle storing the memories. The **striatum**, for instance, is an important part of the brain for forming new habits (that is right, making a new habit is a type of memory). When you learn to tie your shoes and no longer have to think very hard to do so, this type of memory is stored in the striatum. When you smell pumpkin pie wafting out of the oven and suddenly remember being with your family during the holidays last year, this odor memory is stored in your **olfactory cortex**. When you are at a really cool place and listening to some music you love, those memories are stored in your visual and auditory (seeing and hearing) brain areas. When all these different brain regions become activated during complex experiences, the amygdala tells the hippocampus to keep a record of those regions that were involved during the event. These regions can then be reactivated later, when you remember.

Scientists have even figured out how this communication between the amygdala and other brain regions works at the most basic level! Each brain region is made up of small cells called **neurons**, which can send signals to each other. Much like you can send texts to communicate with family or friends that live in other cities and

STRIATUM

A brain part important for movements and motor memory. It allows complex movements like kicking a soccer ball or tying your shoes to eventually become almost automatic.

OLFACTORY CORTEX

The brain region essential for sense of smell. It can store memories related to different scents.

NEURONS

Cells in the brain that act like messengers; communication between neurons helps us learn, remember, move our bodies, see, hear, smell, and other important functions.

states, neurons in the amygdala can send electrical messages to the neurons in the hippocampus, telling them to save an experience. The amygdala can also communicate with the hippocampus to save a memory by influencing **proteins** that are important for memory. When your amygdala is activated by an emotionally intense experience, the amygdala's electrical signals can activate chemical signals causing memory proteins to be produced in the hippocampus. These memory proteins strengthen the connections between neurons [8]. Connections between neurons are what make a strong memory that you can easily recall. We think that both the electrical and protein communication between the amygdala's neurons and other parts of the brain are what helps these memories to be saved and not forgotten. However, because these experiments are difficult to do in humans, more research is needed to explore this idea.

PROTEIN

A molecule that makes up many body tissues and is also important for forming memories. Memory-related brain proteins can make the connections between brain cells stronger to help strengthen memories.

CONCLUSION

Some things that occur in our daily lives are more memorable than others, and the amygdala is essential for clicking "save" on all the pieces of these experiences. When something eventful happens to us, norepinephrine gets released into the basolateral amygdala, activating it and causing the neurons there to send messages to other brain regions, like the hippocampus, to remember that experience for later. Even though many brain regions are activated by an experience, the amygdala can tell the hippocampus to keep a record of those regions, so they can be reactivated later when you need or want to remember the event. Scientists are still studying the ways the amygdala is important for saving our experiences, so they can better understand how the brain makes long-lasting memories. This kind of research is not only important for understanding how the brain works, but might also help us develop treatments for people with memory problems who have lost the ability to make new memories or remember old memories. After all, memory is a critical part of how we know who we are and how we define the world around us. The brain's "save" button, the amygdala, allows us to capture the unique and important experiences that happen in our lives, so we can make good future decisions.

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YOUNG REVIEWERS

HELENA, AGE: 15

My name is Helena and I am 15 years old. I spent 2 years in the US when I was younger where I discovered my passion for the English language. I love writing and listening to poems, and longer bike trips. I am also incredibly fascinated by all sorts of sciences but particularly genetics, microbiology, neuroscience, and psychology.

UC IRVINE BRAIN CAMP, AGES: 11–15

We are students participating in UCI Brain Camp, a summer program at the University of California. We enjoy learning about the brain from scientists at the Center for the Neurobiology of Learning and Memory (CNLM) and love reading and reviewing Frontiers for Young Minds articles.

AUTHORS

KRISTA L. WAHLSTROM

I am a postdoctoral research associate in the Immersive Neuromodulation and Neuroimaging Laboratory in the Department of Psychology at The University of Utah. I received my college degree in biology and psychology from Luther College in Decorah, Iowa, and my doctorate in psychology from the University of Iowa. I am interested in how the amygdala helps us make long-lasting memories and the ways that electrical stimulation of the human amygdala can enhance some types of memory. Outside of the lab, I love to play soccer, scuba dive, go hiking, play the piano, and sing. *krista.wahlstrom@utah.edu

CORY S. INMAN

I lead the Immersive Neuromodulation and Neuroimaging Laboratory in the Psychology Department at the University of Utah. I received my college degree in psychology from Georgia State University and my doctorate from Emory University. I completed my first postdoctoral fellowship in the Neurosurgery Department at Emory University and a second postdoctoral fellowship at UCLA. I have broad interests in helping to establish approaches that push our understanding of emotion and memory from the laboratory into the wild, real world. Outside of the lab, I spend my time playing with my two kids, playing basketball, playing guitar, and going on outdoor adventures like white water rafting, snowboarding, hiking, and climbing.