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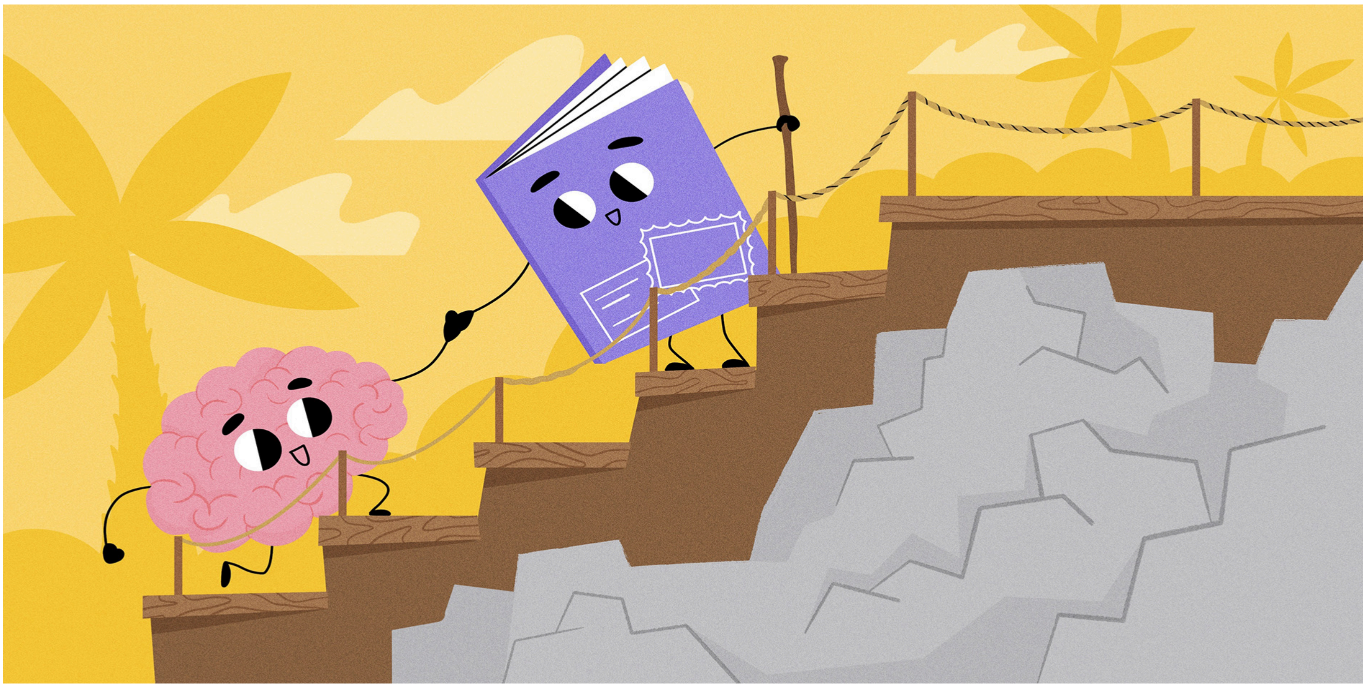

HOW THE BRAIN AND MEMORY GROW UP TOGETHER

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YOUNG REVIEWERS:

ASHLYNN
AGE: 12

CLAIRE
AGE: 14

We forget a lot about events that happen early in our lives. Why does this happen? To answer this question, we looked at how memory changes as children grow. We know the brain is important for memory, but we wanted to understand whether it was the changes in the brain that help kids to remember *or* if it was the ability to remember that changes the brain. We gave kids memory tests and looked at their brain activity across 3 years. Then we asked which changed first—kids' memories or kids' brains? We found that there was an interactive relationship: in younger kids, memory shaped the brain; but in older kids, memory and the brain shaped each other. These results help us understand why memory gets better as kids grow up and how using our brains helps us to remember.

DO YOU REMEMBER YOUR LAST BIRTHDAY PARTY?

Most people can remember their last birthday party. You may remember everything about yours, like the activities you did, who was there, and the kind of cake you had. But do you remember your fifth birthday party? Or your second? Most people do not remember these events and, even if they do, they cannot seem to remember as much detail. Why does that seem to be the case? What happens to our early memories? Research has shown that early memories are fragile and often forgotten, and lots of factors can influence what people remember! People tend to remember emotional events better than non-emotional events, and to remember unique experiences better than non-unique experiences. A 25-year-old can remember their twentieth birthday, but a 10-year-old might not recall much about their fifth birthday. We study children to understand how memories are formed and why early memories are often quickly forgotten. Because young children's brains are developing, we can track changes in **memory** as they happen in real time, and try to link those memory changes to changes in the brain [1].

MEMORY

Thoughts and experiences collected in a person's brain, which they can retrieve at a later date.

LONGITUDINAL STUDY

A study that follows the same group of people over a long period of time. This allows the researchers to understand how something, such as memory, changes over time.

When attempting to link changes in memory to changes in the brain, one question is: which changes first, the memory or the brain? This is kind of like asking "which came first, the chicken or the egg?" To answer this question, a **longitudinal study** is necessary, meaning we had to follow the same kids over a long period of time, measuring their brains and their memories as they grew—and that is just what we did.

HIPPOCAMPUS

The brain area that is in charge of everything memory related. The hippocampus allows the brain to create memories and store them for a long period of time.

HIPPOCAMPUS NETWORK

The group of brain areas that connect to the hippocampus. These interactions are important for the hippocampus to do its job creating memories.

We focused on a specific part of the brain that is most important for the formation of new memories, called the **hippocampus** [2]. To create strong memories, the hippocampus connects to other parts of the brain, which we can think of as a **hippocampus network**. Our question was: which comes first—a mature hippocampus network or a mature memory ability? To phrase the question in a slightly different way, does memory improve because the hippocampus network matures, or does the hippocampus network mature as a result of memory improving (Figure 1)?

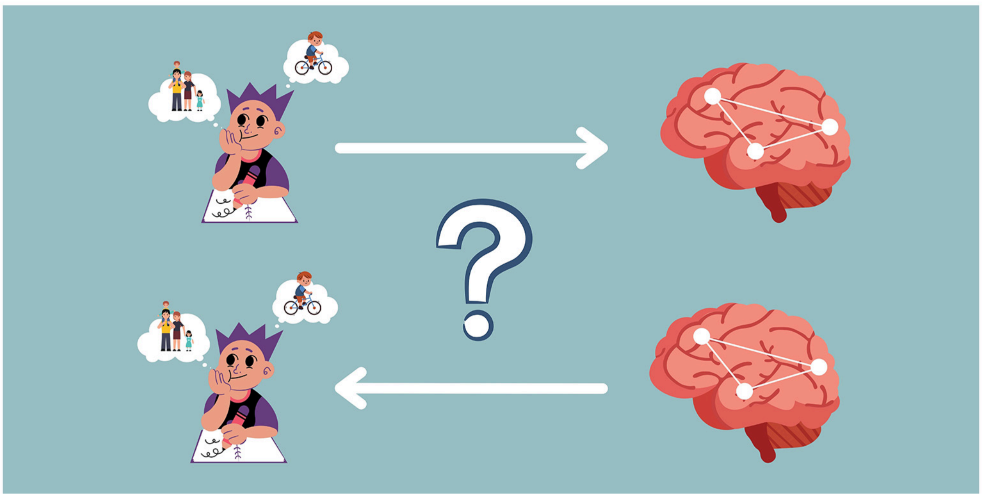

Figure 1

Figure 1

How can we tell whether memory influences the brain, or whether the brain influences memory? This is the question we focused on in our study.

EXPERIMENT TIME—PLAYING GAMES TO MEASURE MEMORY

We asked 200 children from 4 to 8 years old to participate in our study. We followed 100 of these children for 3 years, asking them to come back every year. This longitudinal study allowed us to look at how memory and the brain changed in these children over time. We chose this age range because big improvements in memory take place during those years.

To measure memory, we used a trivia game (Figure 2) [3]. In the game, the children learned six new facts from a person and six new facts from a puppet. Example facts included "The most popular name for a pet is Max" and "Cheetahs are the only big cats that cannot roar." The children were told to remember the facts for a test the following week. The next week, the children answered 22 trivia questions—some were things they learned the week before, some were things they had never learned, and some were things they usually knew. For instance, they usually knew the color of the sky, but they had not learned the names of the bones in the human body. In a surprise twist, we also asked children if they could remember where they learned the facts or how they knew them. We wanted to know if the children remembered not only the facts from the previous week, but whether they remembered who they learned it from (puppet or person). This is the type of detailed memory that allows a person to remember not only their fifth birthday party, but also who was there and what they did! This early detailed memory is also the type of memory we think develops and grows in early childhood.

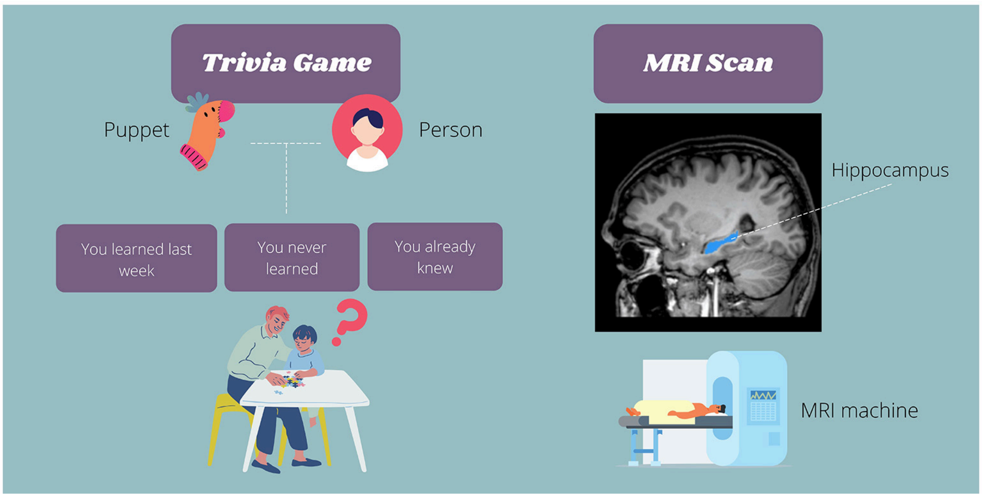

Figure 2

Figure 2

Our study consisted of a trivia game to test children's memories and brain pictures taken using an MRI scanner. On the right, you can see what a brain picture looks like! The blue highlighted region is the hippocampus.

TAKING VIDEOS OF THE BRAIN

We also took pictures of children's brain activity, to see how well the hippocampus network was connected to other areas of the

MAGNETIC RESONANCE IMAGING (MRI)

A scanning device with a large magnet that takes videos of a person's brain by tracking blood flow.

brain—such as the frontal cortex, which is located behind the forehead [4, 5]. We used a brain camera called a **magnetic resonance imaging (MRI)** scanner (Figure 2). This machine looks like a large doughnut! The MRI scanner makes beeping noises while it measures how much blood is going to various parts of the brain. When parts of the brain are working hard, they require more blood (just like when you run, your muscles need a lot of blood and oxygen). Looking at how much blood and oxygen were used in memory-related brain regions allowed us to know how strong the hippocampus network was at that exact point in each child's life.

We used the MRI scanner to measure the strength of the connections between the hippocampus and other parts of its network every year in each child, just as we measured the ability of the children to recall facts every year. This way, we could ask our important question: what changes first, the memory or the brain?

WHAT DID WE FIND?

First, we found that the ability of children to remember the facts we taught them AND to remember who they learned those facts from became better with age. As you might have guessed, older children were better than younger children at remembering. Second, we found that the hippocampus network grew stronger connections with age. Older children had stronger connections than younger children did. Finally, we looked at how memory and hippocampus network connections changed together as children grew. This was to answer our question: which matures first, the hippocampus network or the memory?

Well, it turns out that the answer is both—but the ages of the children mattered. In younger children, memory improved first and led to stronger brain connections later. In older children, it was both—not only did improvements in memory lead to stronger brain connections *but* stronger brain connections *also* led to better memory! From these findings, we concluded that there was an age-dependent, interactive relationship between memory and brain development: in younger kids, memory shapes the brain; but in older kids, memory and the brain shape each other.

We think this means that younger children need to "exercise" their memories to properly strengthen the hippocampus network. This is similar to the way that people need to keep exercising their muscles to make them stronger. However, when children are older and the hippocampus network is stronger, the strength of the network can predict how much the children's memories will improve in the future.

WHAT DO OUR RESULTS HELP US UNDERSTAND?

These results suggest that memory and the brain grow together as children develop. They also highlight the importance of timing when it comes to understanding the relationship between memory and the brain. It seems that, when we are very young (before 6 years of age), memory experiences are really important for shaping our brains. Later in childhood (after 6 years of age), experiences remain important and continue to shape our brains, but our brains also begin to shape what and how we remember (Figure 3). In short, childhood is a critical time for the hippocampus to grow and form brain connections based on experiences. Later in development, the brain and memory have an interactive relationship—experiences help shape the brain, and the brain helps shape our experiences!

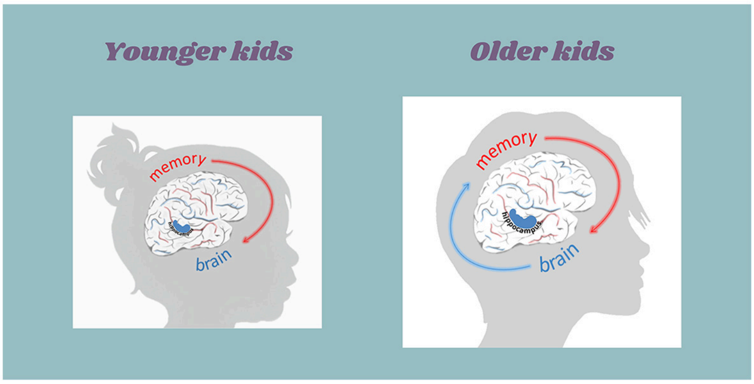

Figure 3

Figure 3

There is an interactive relationship between memory and the brain. In younger children, memory shapes the brain, whereas in older children, not only does memory shape the brain, but the brain also shapes future memory performance. In short, the brain and the memory affect one another and both are important, but these relationships change as children grow up.

Moving forward, more research could be done to understand whether other brain regions are involved in remembering information, since our study focused on just the hippocampus. There is also evidence that boys' and girls' brains develop slightly differently, and although our current research question did not focus on sex or gender differences, this is another possible area for exploration. We hope that the results we find in healthy children can help us better understand the way children learn and develop. These findings could be compared to findings in children with brain differences, or who have challenges with certain types of learning, and may eventually help create therapies for help kids who struggle with memory—which is essential for many subjects in school! Finally, our results suggest that we do not have to simply "wait around" for our memories to get better—the more we use our memories as we grow, the better our memories will be!

ORIGINAL SOURCE ARTICLE

Geng, F., Botdorf, M., and Riggins, T. 2021. How behavior shapes the brain and the brain shapes behavior: insights from memory development. *J. Neurosci.* 41:981–90. doi: 10.1523/JNEUROSCI.2611-19.2020

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YOUNG REVIEWERS

ASHLYNN, AGE: 12

Hi my name is Ashlynn! I play soccer, swim, golf, ski, and love to crochet. I have a dog named Maple and 2 brothers. I love to travel, eat, bake, and sleep.

CLAIRE, AGE: 14

Hello! I am Claire! My preferred subjects in school are English and Math. I have a 6 year old Cockapoo (dog) named Taffy. I love going on walks in the park and my favorite season is winter, because I love snow.

AUTHORS

ANGELA JI

Angela first discovered the field of psychology while studying at the University of Pennsylvania. She was conducting research with monkeys and piglets to learn more about the brain! Then, she discovered her passion for working with children while serving as a lab manager at the University of Maryland. Currently, Angela is studying at James Madison University to become a school psychologist so that she can continue to learn about and help kids. *angela.ji1073@gmail.com

MARY LORENZ

Mary has been interested in science since she was a little kid, but started learning about psychology in high school. It made her want to take more psychology classes in college at the University of Maryland. Then, she joined a psychology lab and got to help with research. Mary is still in that research lab and has worked on even more projects. She is getting a Master's degree in public policy to hopefully connect psychology research with government.

SIGALLE BAHARY

Sigalle first became interested in psychology and the brain when she was in high school. At the University of Maryland, she majored in psychology and got to work on interesting research projects about how people's brains develop and change. She now uses her psychology background to understand businesses and what their customers need. In the future, she hopes to go back to school and learn even more about psychology and the brain.

TRACY RIGGINS

Tracy Riggins is an Associate Professor in the Department of Psychology at the University of Maryland. She received her Ph.D. from the Institute of Child Development at the University of Minnesota and postdoctoral training from University of California, Davis and the University of Maryland, School of Medicine. The goal of her research program is to provide better understanding of the neural bases of cognitive development, particularly in the domain of memory during early childhood. The empirical research conducted in her laboratory involves both typically developing children and children at-risk for cognitive impairments and uses a combination of behavioral, electrophysiological, and neuroimaging methodologies. She is currently serving on the Editorial Boards for *Cognitive Development* and *Developmental Cognitive Neuroscience*.

†These authors have contributed equally to this work