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# FOCUSING IS HARD! BRAIN RESPONSES TO REWARD IN ATTENTION DEFICIT HYPERACTIVITY DISORDER

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Have there been times when you just couldn't focus on homework or wait for your turn to speak? We all have these experiences! But for some children and adults, focusing, sitting, or waiting is extra hard, and that gets them into trouble all the time. They may have something called, attention deficit hyperactivity disorder (ADHD). But why is it harder for them to do these things? We thought that perhaps a part of their brains might work a little differently. So, we looked inside the brains of college students to see their brain activity. We found that, for the students who had ADHD, one brain area was not very active when they were *waiting* for good things. When the brain sends signals that "good things are coming soon!" this helps us wait or focus, even during boring tasks! For those with ADHD, these signals might be weaker, making it harder to wait and focus.

## WHAT IS ATTENTION DEFICIT HYPERACTIVITY DISORDER (ADHD)?

Have there been times when you just couldn't stop wiggling in your seat, playing with your pencil, or looking out the windows instead of doing your homework? Your mom or teacher called out your name because you were not paying attention? You want to tell your stories at dinner and waiting for your sister to finish her story first is hard, isn't it? We all have these experiences, but for some children and adults, this happens very often and gets them into trouble more than other people. Some of these children and adults may have **ADHD**, which makes it really hard for them to focus on things (especially boring things!) for as long as they need to.

**ATTENTION DEFICIT HYPERACTIVITY DISORDER (ADHD)**

A disorder characterized by persistent and developmentally inappropriate levels of inattention, hyperactivity, and impulsivity that impair daily functioning. For children and adults with the disorder, focusing, sitting, or waiting is extra hard, and that gets them into trouble more often than other people. Some scientists think that some parts of the brain may work a little differently for those with ADHD.

## IS THE CAUSE OF ADHD IN THE BRAIN?

Scientists haven't figured out exactly why some people struggle to focus or to stay still more than others. Many things, like the genes we got from our parents or the environment we grew up in, make us each unique and cause us to behave differently [1]. While our brains are all built the same way, each person's brain works a little bit different. Some scientists think that the way chemical messages are sent in some parts of the brain makes it harder for some people to focus or wait, like children and adults with ADHD [2]. They don't mean to bother their friends or make their teachers or parents mad by not focusing or waiting, but it is just so much harder for them.

## WHAT DOES THE BRAIN DO TO HELP US FOCUS?

Scientists think that several parts of the brain may be associated with the symptoms of ADHD. Right in the center of the brain, there is a part called the **striatum**—say it like "strai-ay-tuhm." This part of the brain becomes more active in response to experiences that are fun, tasty, or new. The striatum is made up of many **neurons**—neurons are nerve cells with the special function of carrying messages throughout our brain and body. So, when we see, hear, taste, or feel things that we enjoy, the neurons in the striatum become excited! The striatum is an important part of the brain that helps evaluate whether something is good and allows us to experience joy and happiness. Some people say it's the "pleasure center" of the brain. The striatum is also able to learn to predict when good things will soon be happening [3]. Have you seen a dog drooling and wagging his tail before you put down the bowl of food in front of him? That's the striatum sending the signals, "The food is coming! Sit there and wait!" (Figure 1).

**STRIATUM**

It is thought as a "pleasure center" of the brain that helps evaluate whether something is good and allows us to experience joy and happiness. It is also able to learn to predict when rewards are coming, i.e., good things that may be happening soon.

**NEURONS**

Nerve cells with the special function of carrying messages throughout our brain and body. For examples, the neurons in the striatum send out signals to other parts of the brain when anticipating or experiencing something that is rewarding.

When you are working on a math worksheet, a similar thing may be happening in the striatum. The worksheet may not be fun, but the last time you worked hard on your math problems, your teacher smiled at you, you got an A, and your mom gave you a huge hug and told you that she was proud of you. The next

**FIGURE 1**

A dog drooling while waiting to eat the bowl of food.

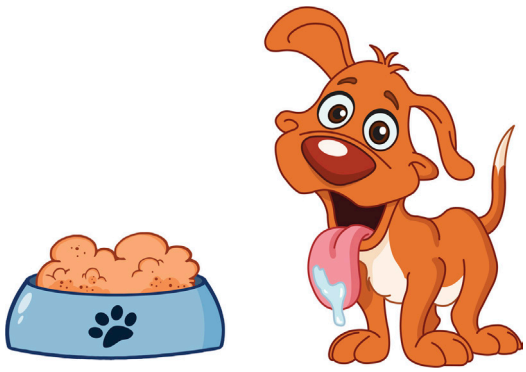

FIGURE 1

**FIGURE 2**

Study participants slide into the magnetic resonance imaging (MRI) machine. The MRI machine uses a large magnet, radio waves, and a computer to produce detailed images of organs and structures within the body, including the brain.

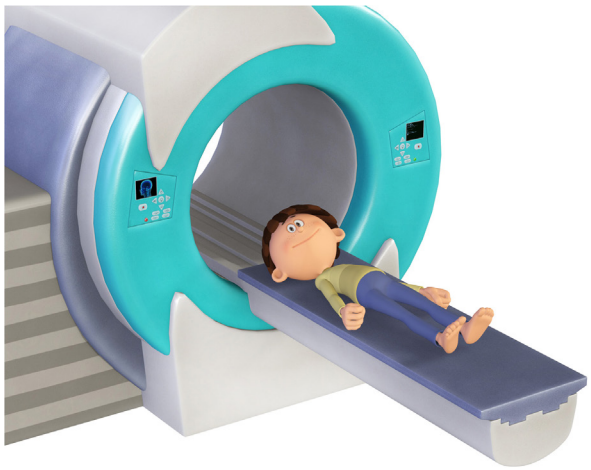

FIGURE 2

**MAGNETIC RESONANCE IMAGING (MRI)**

An MRI machine uses a large magnet, radio waves, and a computer to produce detailed images of organs and structures within the body, including the brain. An MRI machine can keep track of where there is more oxygen in the brain. More oxygen comes in through the blood to the parts of the brain that are more active. So, using an MRI machine, we can see which parts of the brain are more active at a given time.

time you sit down to do a math worksheet, your striatum might start sending signals to tell you good things are coming. In fact, to your brain, it's almost like you are getting those rewards already, because the striatum is becoming active just by expecting the rewards that are coming soon. This action of your striatum helps you keep your focus on the worksheet. The striatum is helping you to behave in a way that got you the positive comments and rewards in the past, so that you can get them again!

## DOES THE STRIATUM WORK DIFFERENTLY IN ADHD?

We wanted to find out if the striatum works differently in people who have trouble focusing or staying still, and in those who are good at focusing [3]. We asked college students (average age = 23 years) in Brazil to help us answer our question. Some of them had ADHD (14 students, 8 males and 6 females) and some of them didn't (15 students, 8 males and 7 females). One by one, they went into a machine called a **magnetic resonance imaging (MRI)** scanner so that we could look inside their brains (Figure 2).

The students lay down in the machine for about 30 min, and they watched a series of images on a computer screen. The screen repeatedly showed a square shape and a diamond shape (Figure 3A). After the diamond shape was shown, sometimes a glass jar with coins appeared. We told them that this meant they would get some money on a gift card each time they saw the coins (they received a gift card at the end of the experiment). But, every time after the square shape was shown, a big X on the glass jar would appear, showing that they wouldn't get any money that time. After a while, most people started liking the diamond shape better than the square shape. That makes sense, doesn't it?

## WHAT HAPPENED IN THE STRIATUM?

When using an MRI machine, we can make it so that the parts of the brain that are active light up in the image of brain that we see. How? In the brain, there are billions of neurons that send and receive messages. Neurons in the

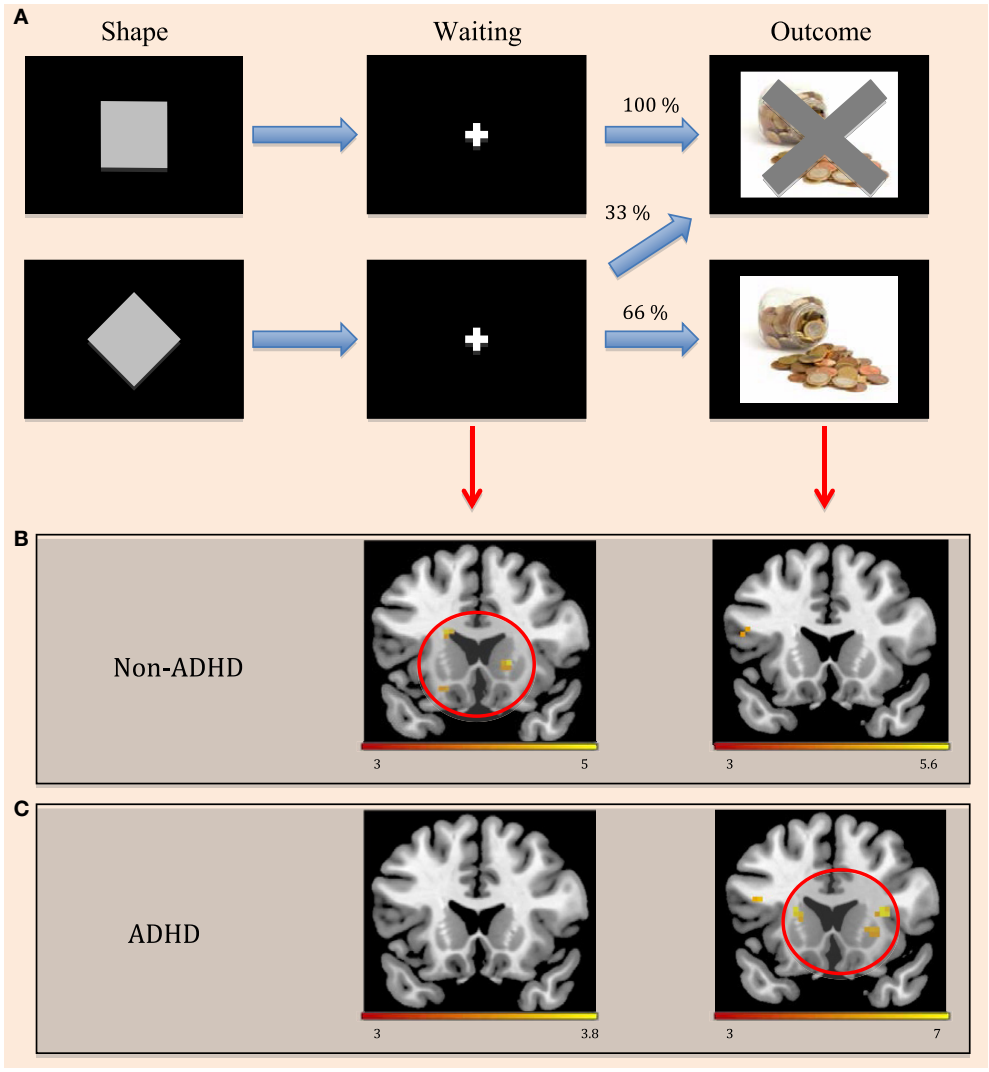


FIGURE 3

**A.** Students saw a series of images on the computer screen in the MRI machine. The square shape was never followed by a reward outcome (the jar of coins). The diamond shape was followed by a reward outcome 66% of the time. **B.** These are the pictures of the brain when you slice it from the top to the bottom, dividing the brain into front and back parts. For students who didn't have ADHD, you see places in the striatum (where the red circle is) lighting up (colored areas) during the period of waiting, but not during reward. **C.** For students who had ADHD, you see places in the striatum (where the red circle is) lighting up when they actually saw the jar of coins, but not while they were waiting for it. In both panels **(B,C)**, the lighter yellow color shows greater activation. Figures adapted from Furukawa et al. [4].

different parts of the brain become more active in response to certain things. For example, the neurons in the striatum respond to things that are rewarding (e.g., food, money, a smile) or when waiting for good things, remember? When neurons become active, they need a lot more oxygen! It's a little bit like when you run, you breathe harder to get more oxygen. More oxygen comes in through the blood to the parts of the brain that are more active. An MRI machine can keep track of where there is more oxygen at a given time. So, when the college students saw different shapes and outcomes, we could see when there was more oxygen in the striatum—the MRI machine could show us this by making the active parts of the brain light up in the image we observed.

For the students who did NOT have ADHD, the striatum lit up (became more active) when they saw the diamond shape and waited for the coins to appear (Figure 3B; showing average activation of the students who didn't have ADHD). This meant that the striatum was becoming more active when they saw a cue that signaled "good things are coming soon!"

On the other hand, in the students who had ADHD, the striatum didn't light up as much when they saw the diamond shape, even though it was showing that coins (reward) might be coming soon (Figure 3C; showing average activation of the students who had ADHD). But the striatum became active whenever they actually saw the jar with the coins. So, the striatum responded when they actually *received* the reward, but not while they were *waiting* for the reward.

We also noticed that, toward the back of the brain, an area called the insular cortex also lit up (outside the red circle, on the far left, in Figure 3) when the students saw the picture of the coins. This occurred for those who had ADHD and for those who did not have ADHD. The activity in this area is thought to be related to remembering rewards. Perhaps seeing the picture of the coins reminded the students of receiving money in the past. We do want to be little careful interpreting this activation, because we didn't think about this before the study. But, it is interesting that some brain activations are similar between the people with ADHD and those without it, while some activations are different, isn't it?

## WHAT DOES THIS MEAN FOR CHILDREN AND ADULTS WITH ADHD?

If you have ADHD, the striatum may not be as good at helping you focus or wait. Without those brain signals telling you that good things are coming, it's hard to keep doing things that are challenging or not so much fun.

If you have ADHD, the striatum may also be reacting more to actual rewards around you instead of rewards coming in the future. This could be another reason why it is hard to focus. For example, you might see a fire truck go by outside your window, and that's exciting—at least more exciting than your

math worksheet! You might hear your little brother playing and laughing and think that you could be missing out on some fun things. Maybe you poke a friend next to you and she jumps in her seat, which makes you laugh. When you skip ahead in a line, you get your favorite food more quickly.

The results of our experiment suggest that, for children and adults with ADHD, these fun and exciting events activate the striatum more. Actual rewards get the striatum excited. But, for people who *don't* have ADHD, the striatum becomes more active in response to signals that rewards are coming in the future. Anticipating rewards gets their striatum more excited, even *before* the actual rewards arrive!

This difference in how the striatum works is important, because all of us, humans and other animals, tend to repeat behaviors that are rewarding. If the striatum sends chemical signals that "good things are coming," even tasks that aren't very enjoyable can be experienced as rewarding. Then, you are more likely to do the same thing again! For example, you work hard to finish a worksheet and the teacher gives you a big smile. The next day, your striatum may already start becoming active *during* the time you are completing your worksheet, because your brain is expecting that smile, and this helps you keep your focus on the worksheet. But people with ADHD may be more likely to repeat the behaviors that got them actual rewards *right away*, like getting a good laugh from their classmates or getting a slice of pizza quickly by skipping the line. The problem is that these may be seen as not-so-good behaviors at times.

It's also important to remember that several brain parts are connected to each other and some of these parts, in addition to the striatum, may play a role in ADHD. One part of the brain that some scientists focus on is the prefrontal cortex. This area of the brain is thought to act like a conductor in an orchestra—it helps coordinate the activities of the different parts of the brain, which makes it easier for you to plan and organize things. There has been some research suggesting that the prefrontal cortex may also work differently in people with and without ADHD. This may explain why some people with ADHD have difficulty following through with tasks they are supposed to do! But, in our study, we wanted to focus on how people with ADHD respond to rewards. So, we chose to look at the striatum, because we know from other research, this part of the brain is very involved in the processing of rewards. We think that our study shows one important aspect of ADHD, although there are many other aspects also worth studying.

## WHAT CAN YOU DO IF YOU OR SOMEONE YOU KNOW HAS ADHD?

As we said in the beginning of this article, we still need to do a lot more research to figure out exactly why some people have ADHD. What we found

in the striatum could be only one of many reasons that some people have more difficulty focusing or waiting. It is not that the striatum is not working. It just seems to work a bit differently in people with ADHD. So, that means that people with ADHD should do things differently in order to accomplish what needs to be done at home or at school!

If you have trouble focusing, try talking to your parents and teachers about it, to see if they can help you create conditions that make it easier for you to focus, such as finding a quiet spot to do your homework, turning off the TV and cell phone, and keeping your brother out of your room! Also, look for ways to build in opportunities to get actual rewards quickly and often. For example, you can break up your work into small chunks, like five math problems at a time. Then, stop to show your work to your dad, congratulate yourself for doing a good job, stretch, and walk around, and then try the next five problems. Ask your teacher to give you a pat on your back when you are doing a good job focusing [5]. Ask the grown-ups around you to be a bit more patient and remind you what you are supposed to be doing, if they find you distracted by other fun or more immediately rewarding things.

Sometimes things are hard when you have ADHD. But managing the rewards around you might help the striatum to become more active in ways that could help you accomplish what you want! It is also hard sometimes when someone you know has ADHD—you may like the person, but he or she can be annoying at times. It's ok to say how you feel and gently remind the person of a good way of behaving. And when the person is doing a good job focusing or waiting, let him or her know that!

You should know that there are a lot of people who are not good at focusing and have ADHD, but are successful and have done amazing things in their lives, like becoming scientists, doctors, chefs, actresses, business owners, and even Olympic swimmers!

## ORIGINAL SOURCE ARTICLE

Furukawa, E., Bado, P., Tripp, G., Mattos, P., Wickens, J. R., Bramati, I. E., et al. 2014. Abnormal striatal BOLD responses to reward anticipation and reward delivery in ADHD. *PLoS ONE* 9(2):e89129. doi:10.1371/journal.pone.0089129

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Champions of Science exclusively serves underserved middle school students from the Oakland Unified School District. Champions of Science develops students' knowledge and excitement about STEM and gives participants exposure to various careers.

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I grew up in Tokyo, studied psychology in USA, and now work as a researcher for the Okinawa Institute of Science and Technology in Japan, with scientists from all over the world. I love that we get to wonder about how our brains work and why we behave in certain ways,

test our ideas, and communicate our discoveries with other people and kids. I hope our research on ADHD will someday make positive contributions to some lives—however small that may be. I am learning new things everyday through my work, watching plants grow, mixing different ingredients in cooking, and picking up new musical instruments.
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I am a Ph.D. student from Federal University of Rio de Janeiro and D'Or Institute for Research and Education. My research is mostly focused on human behavior and neuroimaging. My current Ph.D. project aims to comprehend the representation of motivations in the brain using neuroimaging and behavioral measures. Apart from research, I like samba music and hiking around Rio de Janeiro.

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I am a professor at the Okinawa Institute of Science and Technology (OIST) Graduate University in Okinawa, Japan. I am trained as a clinical psychologist and a neuroscientist. In our lab, we study the nature and causes of ADHD, especially how children with ADHD respond to receiving rewards. So, every day we get to hang out with really cool kids and their families. When I'm not working I love to read novels, watch movies, and travel to new places with my family.

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I graduated in medical school in 1984 and received Ph.D. in Psychiatry at the Federal University of Rio de Janeiro, where I am now a professor. I am also the Coordinator of Neuroscience at D'Or Institute for Research and Education in Rio de Janeiro, Brazil. I love to travel and discover new places, people, and cultures.

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