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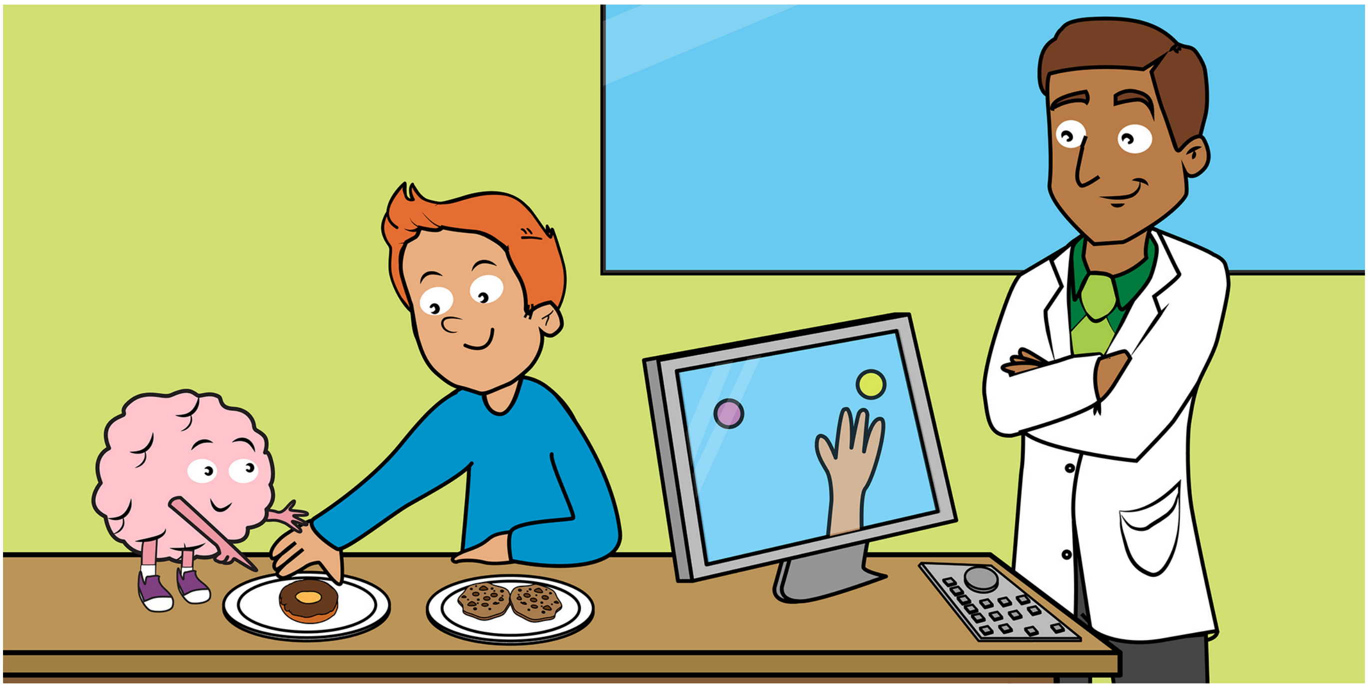

WHAT CAN MOVEMENTS TEACH US ABOUT BRAIN FUNCTION?

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YOUNG REVIEWERS:


BRYSON
AGE: 8


JX ZHANG
AGE: 16


SHARLYN
AGE: 9

Humans typically make thousands of movements every day, which allow us to navigate and interact with the world around us. The brain controls the body's movements and, amazingly, can instruct the body to move in just a split second. Even though the brain can rapidly move the body, most of our movements appear very smooth and efficient. While some movements are easy or automatic, such as blinking our eyes, other movements are more challenging, such as moving the arm to choose between two toys. Scientists know that the brain functions in separate ways for different types of movements. Hidden in our movements, however, lies valuable information that can provide clues about how the brain works. Scientists are using a recent technological advance, called movement tracking, to better understand brain functions such as decision making, attention, and memory.

HOW ARE MOVEMENTS AND THE BRAIN RELATED?

We depend on our bodies to move and interact with the world around us. You may know that the brain controls the ability to move. Even simple activities like picking up an object or running through a playground require the brain to quickly coordinate many body movements. Quick movements can occur because the brain and body are tightly linked. Scientists call this linkage the **brain-body connection**. Because of the brain-body connection, we can seamlessly move from one moment to the next moment. For example, when riding a bike, your brain continuously communicates with your body, telling it how to stay upright while pedaling, turning, and stopping. Your brain's job is to constantly update your body's actions on the bike, so that you do not fall off.

BRAIN-BODY CONNECTION

Pathways that allow for communication between the brain and body.

You might think that simpler movements, like reaching out your hand, are easy to make. This is not always the case. For example, imagine choosing between two desserts in front of you. When you move to choose between them, it is not just your brain giving your body a one-time command to reach for a dessert—it is an active conversation between your body and brain! We can try this right now. Close your eyes and picture a cookie and a doughnut. Does the doughnut smell good? Is the cookie soft or hard? Do you prefer one of the desserts, or is it a close competition between the two? All these thoughts occur quickly, so your brain rapidly decides which dessert you prefer. As fast as these thoughts are, you often start moving your arm to reach before you have fully decided which dessert you want more. Because the brain and body are so closely connected, scientists believe that studying the details of how we move can help us understand how the brain functions.

HOW SCIENTISTS STUDY THE BRAIN THROUGH MOVEMENTS

Movements and how they relate to brain functions have mainly been studied by observing what we move toward and how long it takes to get there. However, did you know that we rarely make the exact same movement twice, even if both movements are to the same location? For example, each time you reach to open a door, there are almost always small differences in the path your hand takes to the doorknob. Although many of our movements may look identical, there are actually tiny moment-to-moment (less than a split second!) changes in the movement's path.

MOVEMENT TRACKING

A method used to track the path, curvature, and speed of movements from one location to another location.

These changes are hard to observe with just our eyes. Scientists have found a way to record these small and quick changes in our movements by using a method called **movement tracking**. There are a few ways to track movements. Scientists can record movements on a computer screen by using a computer mouse to track the movements

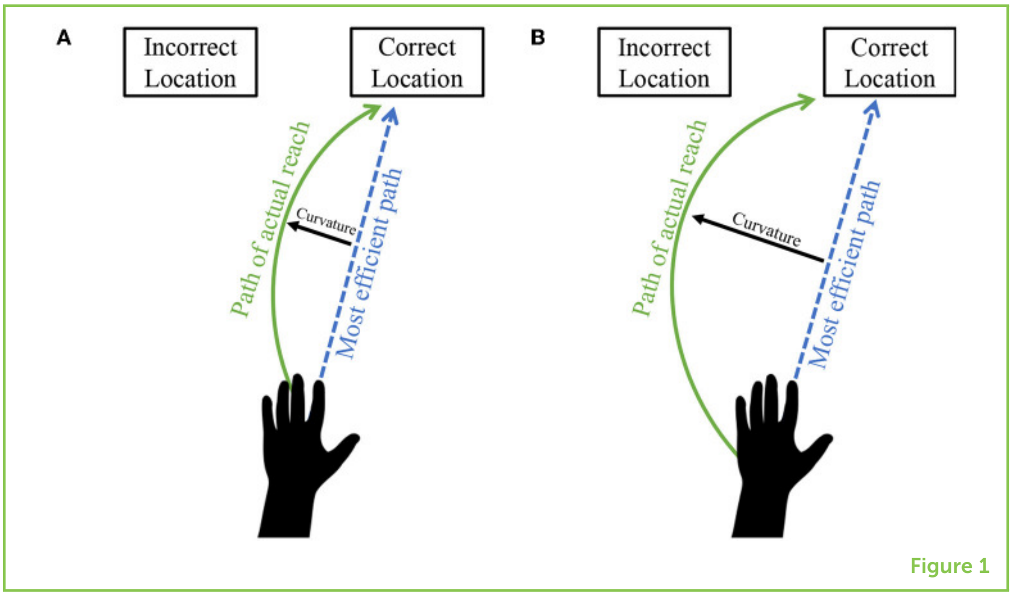

Figure 1

The path of two different movements. Curvature tells us how much the path of a movement is different from the straightest (most efficient) path possible. **(A)** The path of the movement (green line) curves a little from the most efficient path (blue line). This typically means the person is more confident of the correct answer. **(B)** This path curves much farther away from the most efficient path, which means that the person is less confident of the correct answer.

a person makes. They can also use sensors placed on a person's hand. As the hand moves from one location to another, the sensors track the path the hand travels. Movement tracking can provide a lot of detailed information about movements that our eyes cannot see. For example, it can show the **curvature** of the hand movement, which is how much the actual path of the hand differs from the straightest path possible (Figure 1). When the hand curves less, the path is straighter and more efficient. When movements have a lot of curvature, it typically means that the person is less certain about where he or she wants to move.

CURVATURE

How much the actual path taken is different from the straightest possible path.

Why is it important to track and understand the details of our movements? Interestingly, the paths we take when we move have been linked to what our brains are doing. Using movement tracking with **brain imaging** methods, scientists have discovered that the type of path a movement takes may be related to the brain's activity during the movement [1, 2]. Brain activity can suggest how much a person is thinking about one thing (the color red, for example) compared to something else (the color blue).

BRAIN IMAGING

Tools that scientists use to measure brain activity.

We can think about what this means by going back to our example from earlier, in which you were choosing to reach for either a cookie or a doughnut. Imagine that you like both cookies and doughnuts, but you just barely prefer doughnuts over cookies. Scientists have shown that, in cases like this, your hand may curve slightly toward the cookie because you are still thinking about it and considering eating it. However, the hand moves back to the doughnut because the doughnut becomes the preferred choice (Figure 2). This type of movement curvature occurs because of the competition taking place in the brain when choosing between which dessert to reach for and eat. If the choice was instead between your favorite and least favorite food, then your hand movement would probably have very

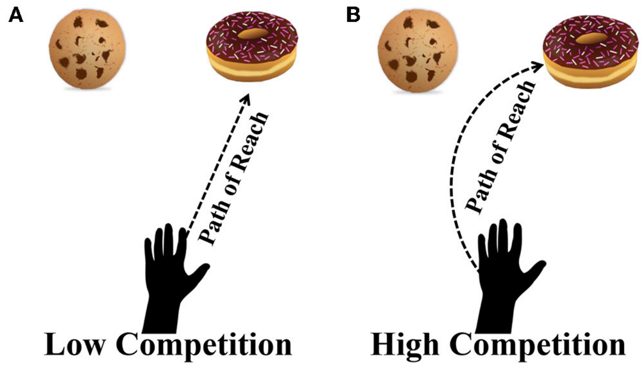

Figure 2

Figure 2

The difference between low- and high-competition movements. Each example shows a reach toward the doughnut, however, there are significant differences between their reaching paths. **(A)** This movement to the doughnut is straight and efficient because there is a clear preference for the doughnut over the cookie. This means there is low competition. **(B)** This movement curves toward the cookie because there is high competition between the two desserts, suggesting it was more difficult for the person to choose.

CATEGORIZATION

How similar concepts are sorted into groups, or categories.

little curvature away from your favorite food. In other words, your movement would be more efficient, since your least favorite food does not compete with (or even come close to) how much you enjoy your favorite food.

MOVEMENTS AND CATEGORIZATION

Our brains are constantly receiving information from the world around us. One way the brain organizes all this information is by using **categorization**, which is how we sort concepts into groups. For example, how would you describe a dog to someone who has never seen one? You might begin by describing a dog as something that fits under the category of an animal, a mammal, or a pet. The person who has never seen a dog could use those categories to gain a better idea of what dogs are. Therefore, categorization is important for sharing ideas and knowledge. Categorization is also important for learning new concepts by relating them to what we already know.

Scientists can study how the brain categorizes information by examining a person's movement paths while he or she is sorting information [3]. For example, imagine you were asked whether a giraffe would fit better into the category of a pet or a wild animal. As your hand moves to decide how to categorize the giraffe, your movement would likely be straight toward the wild animal choice. A giraffe cannot fit into most homes, let alone be a pet! Therefore, there is no competition that would draw the movement of your hand toward the pet category. What about a parrot? Parrots are more difficult to categorize because they can be found as pets or in the wild. How you categorize a parrot depends on which category (pet or wild animal) you think fits better. As you choose a category, your movement might curve more because there is competition between these categories. Based on the amount of curvature in the movement path, scientists can uncover details about how the brain categorizes information.

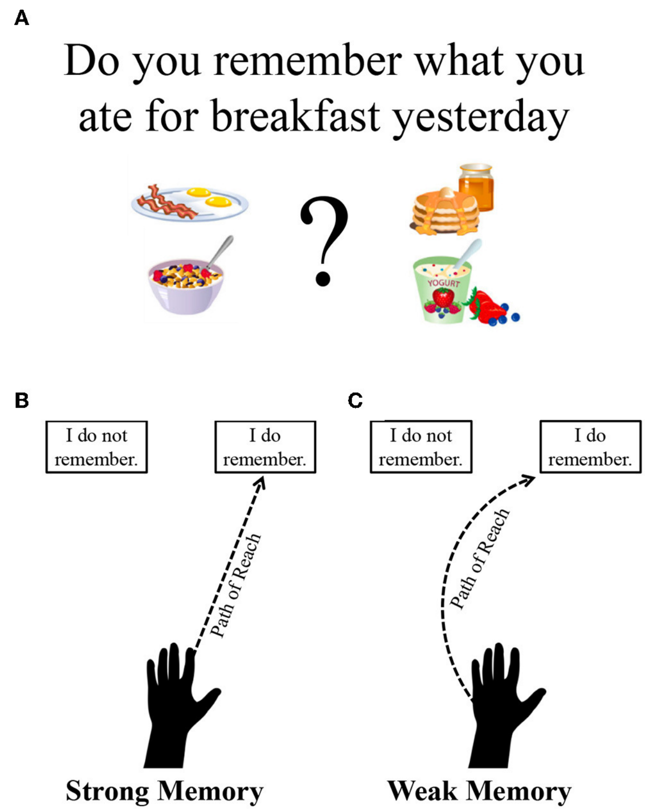

Figure 3

Figure 3

Movements can show strength of memory. **(A)** Imagine you are asked if you remember what you ate for breakfast yesterday. **(B)** If you are very confident in your memory of what you ate, then your hand would move straight and efficiently to the "I do remember" location. **(C)** If you *think* you remember what you ate but are not very confident, then your movement is more likely to curve toward the "I do not remember" option before reaching the "I remember" option. This curvature suggests that the memory of what you ate for breakfast yesterday may not be strong.

MOVEMENTS AND MEMORIES

Memory is another brain function that plays an important role in almost everything we do. Memory allows us to remember and think about past moments, learn from past experiences, increase our knowledge, and shape our personalities. The effectiveness of the brain at forming memories can have a large influence on our everyday lives. Scientists have used movement tracking to study how strongly our memories are formed [4]. Using movement tracking, we can record the path the hand takes as it moves toward either an "I remember" option or an "I do not remember" option (Figure 3A). For example, think about what you had for breakfast yesterday morning. Do you remember? If you do, and you are very confident, then the path your hand takes to respond that you do remember should be straight and efficient (Figure 3B). Alternatively, if you are not confident in your memory of what you ate for breakfast yesterday, but you still move to choose the "I remember" option, then your movement may curve toward "I do not remember" (Figure 3C). More curvature occurs because even though you remember what you ate for breakfast yesterday morning, the memory is not very strong. This method allows scientists to study movements to gain insight into how the brain forms memories.

CONCLUSION

By using techniques such as movement tracking, scientists have learned that the brain and body are tightly linked [5]. Movement tracking data shows us that the brain communicates with the body and updates movements while they are being made. In this article, we reviewed research showing that hidden moment-to-moment changes in our movements can help scientists relate our actions to how our brains function. These discoveries are exciting because they offer a new way to investigate how the brain works. Future work could apply movement tracking to a wide range of research areas to investigate brain functions, including how brain functions develop over time and what goes wrong in certain disorders where movements are impacted, such as Parkinson's disease. In summary, scientists could use movement tracking to better understand the brain and how we interact with the world around us.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

BRYSON, AGE: 8

I am Bryson. I am 8 years old and in the third grade. I like to review the papers because I think that they are fascinating.

JX ZHANG, AGE: 16

Hi, my name is Jx Zhang, and I am a ninth grader residing in Virginia. Drawing and listening to K-pop are two favorite things I do at my spare time. I am full of curiosity about the world and like to explore scientific issues. I believe that technology makes our lives more convenient and better. I also like solving Maths because it gives me a sense of accomplishment.

SHARLYN, AGE: 9

I am Sharlyn. I am in fourth grade at Sias International School. I enjoy reading books and editing videos. I love painting. I believe arts can express one's feelings better than words. I hope that one day my work can be taken to space as a gift for the exchange to signify friendship between humans and outer space civilization.

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