

## NEUROSCIENCE OF SENSE OF AGENCY

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### YOUNG REVIEWER:



**MACKENZIE**

AGE: 15

One important reason for living organisms to have a brain is to produce movement. Movements can be voluntary (those that are in our control, like walking) or involuntary (those that are not under our direct control, like breathing). Our brain is not only responsible for producing these movements, but also for generating the sense of being in control of our voluntary movements. Feeling like we are in control of our movements is called our sense of agency. How is the sense of agency generated? Are we really in “control” of our actions? This article attempts to answer these questions, discusses what happens when our sense of agency is disrupted and concludes with a summary of the current and future research in this field.

### WHAT IS SENSE OF AGENCY?

For hundreds of years now, philosophers and scientists have been trying to understand our ability to “choose” our actions. Most of us believe that the movements we make and the thoughts we create are freely chosen and freely made by our own will. I decide that I want to pick up this pen from the table, and then I do it. This sense

## FREE WILL

The ability to choose your own actions free from any external control.

## SENSE OF AGENCY

The feeling of control over your actions and their results.

## VISUAL CORTEX

The region of the brain that receives and processes visual information from our surroundings.

## FRONTAL CORTEX

The region of the brain that is crucial in decision making.

## SUPPLEMENTARY MOTOR AREA

The region of the brain that plans a movement.

## PRIMARY MOTOR CORTEX

The brain region that generates movements.

of **free will** is a big part of our sense of who we are. There is no scientific evidence till date to believe that there is a free will force that drives our brain to make a movement. In fact, it is the opposite. The sense of having made a freely willed movement is fully generated only after the movement is complete [1]. Therefore, scientists believe that our brain makes choices based on certain external/internal signals and that we only perceive these choices to have been made out of our own free will. The subjective perception or feeling that we are in control of our movements and that we are responsible for its consequences is called the **sense of agency** [2]. Scientists are still exploring how the brain generates the sense of agency and how we get the feeling of being responsible for the movements we make and their consequences.

## THE PREDICTIVE BRAIN

Our brains are complex organs that can make predictions. In fact, we make sense of the world around us based on the ability of the brain to predict. The brain makes predictions by considering our responses to external signals (sound, sight, or smell) or internal signals (hunger, thirst). The brain also constantly updates these predictions as the situation demands. For instance, when you climb a flight of stairs, after a couple of steps you realize that you do not have to see the following step to estimate its height. This is because your brain predicts the height of the steps based on the previous ones, so that you can climb effortlessly even in darkness. However, if there is a small change in the step height, you might trip. This happens because your brain executed a movement based on its prediction that all step heights were equal. On the other hand, if you are walking on a trail, your brain knows that the path is uneven. Therefore, it must depend on your senses to plan your movements and needs to keep updating its predictions. This impressive ability of the brain to make predictions is also the core of the sense of agency [3].

## SENSE OF AGENCY AT WORK

Consider a situation in which you and your friend are outdoors playing catch and he throws the ball toward you. You track the path of the ball, seeing that it has been thrown at a certain angle and at a certain speed to reach a certain height. You move around the field to reach the most suitable position to catch the ball successfully. How do you do this? When you see someone throw a ball toward you, your eyes capture all the information about the ball and send it to the **visual cortex**, a region at the back of the brain. Using this information, the **frontal cortex**, in the front of the brain, predicts the trajectory of the ball and decides which sequence of actions to make. The sequence of actions is triggered by the **supplementary motor area**, which signals the **primary motor cortex** to perform the actions. This “go” signal,

along with inputs from other deeper brain regions, gets refined and reaches the spinal cord. The spinal cord then relays this message to the proper muscles, in this case, the muscles of your hands and feet. As a result, they all move in synchrony, so that you assume the correct position to catch the ball.

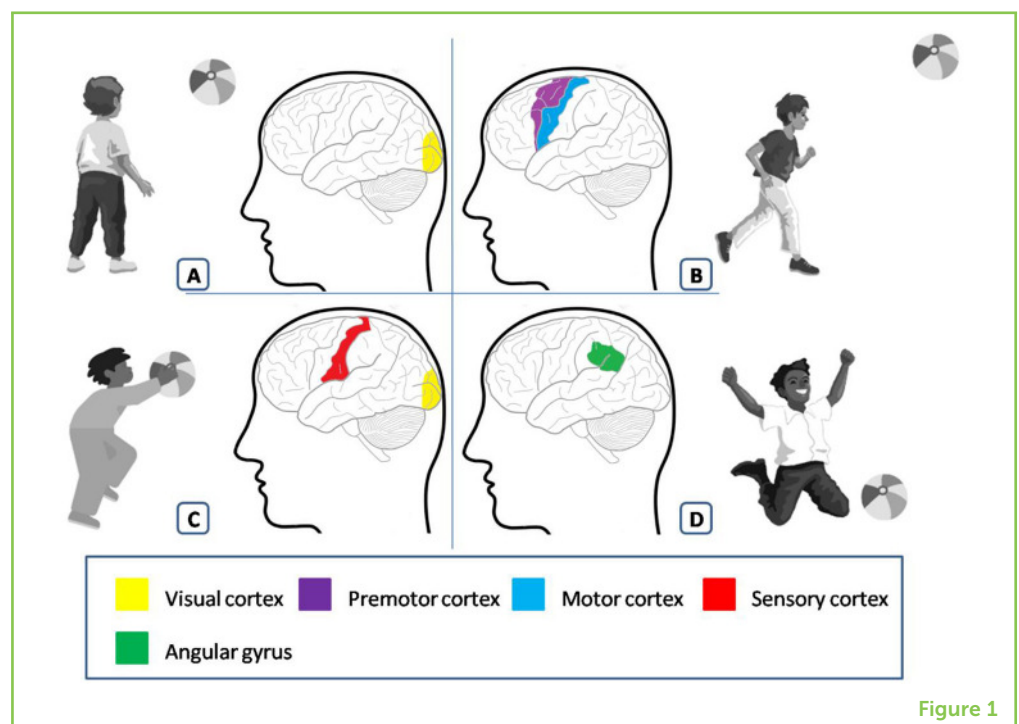
Once you catch the ball, sensors on your skin send feedback signals to the sensory parts of the brain, informing the brain that the ball has been caught successfully. Thus, the action is complete. After the action has been performed, the feeling that *you* made the action—that *you made the choice* to react to something around you and *acted in some way*—is the sense of agency. The sense of agency also includes your feeling of being responsible for successfully catching the ball (Figure 1).

### HOW DOES THE SENSE OF AGENCY ARISE?

How do we end up feeling a sense of agency? Scientists believe that, when the premotor cortex plans an action, a sense of intention is also generated. The planned action is based on the brain's predictions from past events and experiences. Once the planned action is performed, the brain is informed of the outcome of the action through feedback signals. If the predicted and actual outcomes match, then the sense of agency is generated—that is, you feel that the action was under your

**Figure 1**

Brain regions activated while playing catch. **(A)** Your visual cortex captures and processes information about the approaching ball's height, speed, and angle. **(B)** Visual information is sent to your premotor cortex, which plans your movement and signals the primary motor cortex to execute it. You move toward the ball. **(C)** As you catch the ball, sensory information is fed back into your brain via the visual and sensory areas. **(D)** Your angular gyrus performs the comparison between the actual outcome of the action and the predicted outcome. A perfect match between outcomes generates your sense of agency.



**Figure 1**

### ANGULAR GYRUS

A small part of the parietal cortex that senses a mismatch between predicted and actual action outcomes.

### PROSTHETIC DEVICE

An artificial body part that replaces a missing or non-functional body part.

control. In cases where a mismatch occurs between the predicted and actual outcomes, like when the speed of your mouse cursor suddenly increases and overshoots the target, then there is a disruption of the sense of agency, and you feel that you were *not* responsible for the action or its outcome. A brain region known as the **angular gyrus** gets activated when such a mismatch occurs, making you feel that you did not perform that action.

## WHAT HAPPENS WHEN THE SENSE OF AGENCY IS DISRUPTED?

There are certain conditions in which the sense of agency does not work properly. First, starting from about the age of 50, the sense of agency decreases. It declines rapidly between ages 60–80. This decline could be due to the physical limitations that occur as our bodies grow older, or it could be due to age-related changes in the regions of the brain where the sense of agency is generated. Also, patients with a brain disorder called schizophrenia believe that their own movements (and their thoughts) are being driven by external forces. This happens because their brains cannot predict the consequences of the actions that they take. Schizophrenia patients cannot differentiate between actions/thoughts that are self-generated and those that they are made to do by someone else. Patients with a condition called functional movement disorder have abnormal movements or postures that seem voluntary in a doctor's exam, but feel involuntary to the patients. This happens because these patients have lost their sense of agency, so they do not realize that they are the agents of the abnormal movements [4].

The sense of agency also has implications in the field of law, because it is crucial to consider whether a person who committed a crime or wrongdoing was aware of the results of his or her actions, or whether that person acted under a reduced sense of agency, such as in the case of a mental illness. Further, it is important to understand what happens to the sense of agency when we think about human-computer interfaces, like **prosthetic devices** that are controlled by a computer. Is it possible to develop a sense of agency when using such devices?

## CURRENT AND FUTURE RESEARCH

Sense of agency is a phenomenon that has not been studied widely, and the topic has not received the attention it deserves. There are only a handful of scientists around the world who are trying to explore the brain mechanisms that generate the sense of agency. Although we have answers to a few basic questions about the sense of agency, there are a lot more that remain unanswered. Scientists are trying to determine precisely which regions of the brain are responsible for

generating this feeling of control over our movements and how these brain areas are connected with each other.

Upon identifying those crucial regions and their exact functions, the next step will be to develop strategies to alter the activity and connectivity of these regions and examine how these changes impact the sense of agency. Hopefully, the quality of life of older people and of people with a disrupted sense of agency can be improved by this research, by increasing their sense of control over their bodies and their actions.

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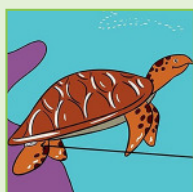
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## YOUNG REVIEWER



### **MACKENZIE, AGE: 15**

My name is Mackenzie, and I enjoy music (both playing and listening), books (fantasy in particular), and sports (my favorite is tennis). I also enjoy science, math, and language, but the thing I enjoy most is backpack camping.

## AUTHORS



### **MANTOSH PATNAIK**

I am a Research Assistant at the National Brain Research Center, India. I developed a fascination for the brain and its functioning toward the end of my undergraduate degree which led me to pursue my Masters in Neuroscience. I often think of how our brain makes all the movements that we make every day like when I play fetch with my two dogs, and play the violin. My research involves understanding the control of movements in healthy individuals and in patients with movement disorders.



### **NIVETHIDA THIRUGNANASAMBANDAM**

I am a clinical neuroscientist working at the National Brain Research Center, India. After I obtained my medical degree, I developed interest in interdisciplinary, patient-oriented research and pursued a Master's in biomedical engineering followed by a Ph.D., in Neuroscience. I am intrigued by the complexity that is involved in the control of our finest movements and what goes wrong in patients with movement disorders. My research uses painless brain stimulation and recording methods to understand human movement control. I hope you will enjoy our article.  
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