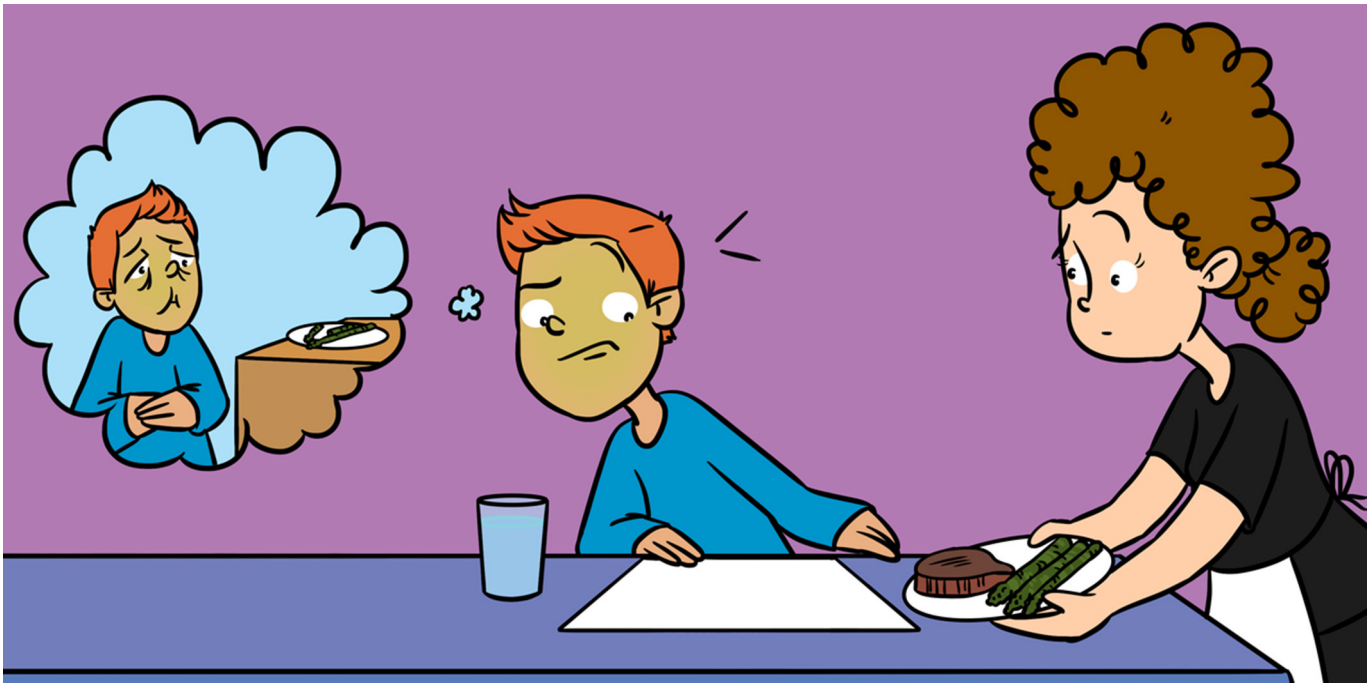
frontiers FOR YOUNG MINDS

NEUROSCIENCE AND PSYCHOLOGY
Published: 20 May 2022
doi: 10.3389/frym.2022.867981



HOW DOES THE BRAIN CONNECT THE WORLD AROUND US TO THE WORLD INSIDE US?

Yoav Livneh *

Department of Brain Sciences, Weizmann Institute of Science, Rehovot, Israel

YOUNG REVIEWER:

HILLEL

AGE: 12

When we are hungry and smell delicious food, things start to happen in our bodies—our mouths water, our stomachs release digestive juices, hormones, and more... all before we even taste the food. How does this happen? Our brains can predict the future. Not through magic, but by learning from past experiences. Our brains are constantly making predictions about the world around us—that is what allows us to catch a ball, ride a bike, and estimate how fast a car is coming so we can safely cross the road. Our brains also make predictions about things inside our bodies. In this article, I will describe how the brain uses information from past experiences to predict what the body will need in the future. These predictions are closely related to the way we experience emotions and feelings, so understanding them may help us better understand and treat various mental health conditions.

THE BRAIN-BODY CONNECTION

The brain and the body communicate with each other every moment, throughout our lives. This communication is essential for our physical

and mental health—but how does it occur? According to traditional theories, when there is any kind of change in the body, such as when we eat or get too warm, our internal sensory systems send a message to the brain. The brain then responds by sending instructions back to the body, such as "start the digestion process," or "start sweating." This is similar to the way our home air conditioners work—when it gets too hot, a temperature sensor sends a message to the air conditioner to cool the room.

Now imagine you are walking down the street. It has been a long time since lunch, and you are very hungry. Suddenly you smell something delicious. The smell of food immediately triggers a complex and coordinated reaction in your body: saliva accumulates in your mouth, digestive juices are released in your stomach, insulin (a hormone important for absorbing sugar) is secreted from the pancreas, and more... all before you take a bite. This example shows how our brain controls our bodily functions, not only in response to actual changes in the body, but also in anticipation of what is *going* to happen. Over a century ago, this phenomenon was identified and studied by the Russian scientist Ivan Pavlov. For his important and ground-breaking research, he was awarded the Nobel Prize [1].

THE BRAIN ANTICIPATES WHAT THE BODY WILL NEED IN THE FUTURE

You may be wondering why our brain needs to predict the future to regulate bodily functions. Many studies have shown that, to maintain our health, the brain must anticipate the body's needs. For example, if we inject food directly into the stomach through a tube, which prevents the brain from predicting that food is coming, the body has difficulty absorbing sugars from the food, creating a temporary condition similar to diabetes. This is because when the food is already inside our bodies, it is too late for the body to start processing it effectively. In addition to digestion, the brain's predictions play an important role in maintaining other bodily functions, such as regulating the amounts of fluid and salt in our bodies.

For our brain to predict our needs and control our bodily functions, it must learn from past experiences. We are talking about *internal* experiences—those that happen inside our bodies. A good example is when we avoid a food that has made us sick in the past. After we get sick from a food, our brain quickly learns to avoid it, and we will feel disgusted when we see, smell, or taste it afterwards. This type of learning is essential for the survival of animals in the wild because it helps them avoid harmful foods and diseases. In fact, this type of learning happens so quickly, and the memory left from it is so strong and long lasting, that scientists use it to study the general mechanisms of learning and memory in the brain.

In these situations, the brain remembers the association between an external event (the smell of a particular food) and an internal event (nausea or stomach pain) (Figure 1). But how does our brain make these associations? And does this process have any significance in addition to controlling of bodily functions?

Figure 1

Our brain connects the world around us to the internal environment of our body. The picture shows a person seeing and smelling a cake. This sensory information then triggers a brain command to the stomach, causing changes such as digestive juice release. Information about these changes and the eventual digestion of food is sent back up to the brain to update it.

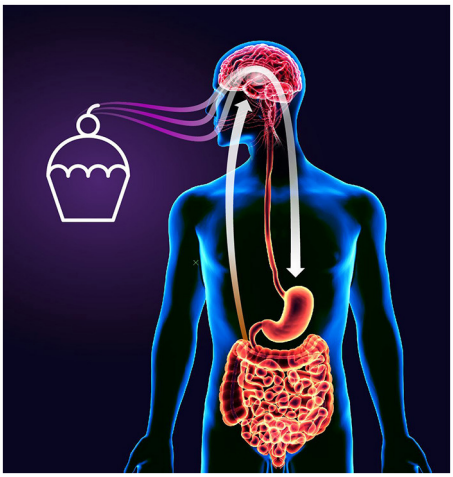


Figure 1

THE INSULA—THE ISOLATED ISLAND IN THE BRAIN THAT CONNECTS THE INNER WORLD TO THE OUTER WORLD

CEREBRAL CORTEX

The outer layer of the brain in mammals, involved in the more advanced brain functions, such as memory, attention, language, imagination, decision making, and long-term planning.

The **cerebral cortex**, the furrowed, thin, outer layer of the brain that lies beneath our skull, is responsible for the more advanced functions of our brain, such as memory, attention, language, imagination, decision making and long-term planning. Hidden in one of the innermost folds of the cerebral cortex is an area called the **insula**. This area got its name because it is hidden so deep inside an inner fold of the cerebral cortex ("Insula" is Latin for "island"), but the insula is not actually isolated. It is connected to, and communicates with, many brain areas (Figure 2).

Figure 2

Illustration of the human brain (left side is the front, and the right side is the back). The cerebral cortex is the outer layer covering the brain, and it has many folds, as shown in the figure. The insula (in purple) is hidden inside the folds and can only be seen when peeking between them.

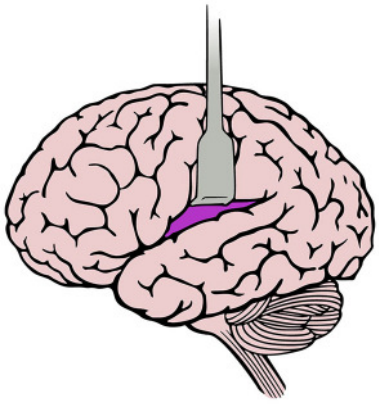


Figure 2

INSULA

A brain area hidden in a deep fold of the cerebral cortex that helps us sense and control bodily functions, experience taste, emotions, and feelings such as hunger and pain.

One of the unique characteristics of the insula is that it receives detailed sensory information about what is happening throughout our body. While other areas of the cerebral cortex receive information through our external senses about what is happening *around* us, the insula identifies what is happening *inside* us.

Our understanding of the cerebral cortex was greatly advanced by the research of the Canadian neurosurgeon Wilder Penfield. In the 1940s, Penfield mapped the function of the various parts of the cerebral cortex as he prepared for surgery on patients with epilepsy. To know where he needed to operate, and where he had to be especially careful, Penfield applied a mild electrical current to the patient's cerebral cortex. He found that stimulating different areas of the cerebral cortex caused reactions in corresponding areas of the body. For example, when he stimulated the "hand area," patients reported feeling something touching their hand. When he stimulated the insula with a mild electrical current, patients reported feeling internal sensations, especially in the stomach area, such as "butterflies" or nausea. In addition, Penfield found that electrical stimulation of the insula activated bowel movements, similar to what happens when we digest food.

NEUROIMAGING

Various technologies like MRI and CT that create an image or map of the structure and function of the brain. Neuroimaging is used for medical and scientific research purposes.

Many years later, **neuroimaging** techniques were developed that allowed researchers to "see" human brain activity as it was happening. Using neuroimaging, researchers found that activity in the insula corresponds to many changes inside the body, such as changes in blood pressure, heart rate, breathing, temperature, and digestion.

SALIENCE NETWORK

A network of brain areas that responds to abnormal and/or significant external events. The network constantly monitors an organism's environment, filtering out stimuli, and identifying significant events.

Moreover, researchers discovered that, in addition to responding to and regulating things going on inside us, the insula also responds to things going on *around* us. In fact, the insula is now considered to be an important part of the **salience network**, which is a network of several brain areas that work together to process information about unusual or significant events happening in the world around us.

In summary, the insula connects our inner and outer worlds, and it learns from past events to anticipate what our body will need in the future, such as learning to avoid foods that have previously made us sick, or seeking out food that it remembers to be tasty and nutritious [2]. Is all this only relevant for eating? And what does it have to do with emotions?

THE INSULA HELPS US PROCESS OUR EMOTIONS

Making connections between external and internal events is also an essential part of how we experience our emotions. Many of our emotions can be characterized by physical changes, such as a racing heartbeat or an increase in blood pressure. There are many theories suggesting that the way we interpret or understand changes in our

body influences—and possibly even determines—our emotional state. For example, if your heart starts to race right before performing on stage for the first time, you may interpret this to mean that you have stage fright. But if the same thing happens after a long run, you will probably just think you had a good workout. Likewise, a feeling of "butterflies in the stomach" or mild nausea could cause you to feel different emotions, depending on the circumstances. For instance, if you became nauseated after eating a lot of cake, you would probably interpret that as, "I ate so much I got sick." If it happened right before you went on stage, however, that same feeling could make you worry that you have stage fright.

Due to its important role in connecting the external and internal worlds, the insula is considered to be an essential part of the brain network that causes our emotional experiences. The main role of the insula in emotional experience is to link signals coming from inside the body (like a slight feeling of nausea or a racing heartbeat) to events happening in the surrounding world (like seeing the audience when you perform for the first time) [3].

Scientists have discovered that changes in insula function are linked to many types of mental health conditions, such as eating disorders, drug addiction, depression, and anxiety. This link is easier to understand now that we know how the insula is involved in processing emotions. Many researchers believe that mental health conditions involve changes in the way our brain responds to what is happening inside our bodies. For example, according to some theories, anxiety is associated with hypersensitivity to signals from within the body, while depression is associated with reduced sensitivity to those signals. Let us look at an extreme example—panic attacks. During panic attacks, people may experience mild shortness of breath, but if they are hypersensitive to events happening in their bodies, even a mild shortness of breath may result in a strong emotional response that will only make things worse. Eventually, they may feel unable to breathe at all. In fact, researchers have found that panic attacks are also associated with changes in insula activity.

In conclusion, there is a growing interest in learning more about the communication between the body and the brain, with the understanding that this communication is vital to many areas of physical and mental health [4].

HOW IS THE INSULA BEING INVESTIGATED TODAY?

How can researchers understand the mechanisms of communication between the body and the brain? When researchers study this, they must take into account that many physical changes are taking place in our bodies all the time, at every moment (such as blood pressure, breathing rate, blood sugar levels, etc.). To conduct an experiment,

researchers must look at each change in the body at a time, by measuring it and controlling it. To study the insula, we change only one variable at a time (such as blood sugar levels, or heart rate) while observing or manipulating the activity of the insula. By doing this, we can understand how the insula responds to the many changes in our body, and how the insula controls bodily functions in response to changes in the world around us.

ANIMAL MODEL

A laboratory animal that is particularly suited for research and can help scientists to understand the biology of other animals and humans.

In my research group at the Weizmann Institute of Science, we conduct these kinds of experiments using **animal models** (mice) and human subjects. Using the latest technology in animal models, we can "read" and decipher complex patterns of activity in the insula, by monitoring hundreds and even thousands of brain cells in real time, as they respond to external and internal events [5, 6]. We can also control the activity of the insula in animal models by dictating the insula's activity patterns. To do this, we use state-of-the-art molecular biology and microscopy techniques. For example, we can record the activity of cells in the insula in response to the smell of food, and identify which specific cells respond to the smell. Then, we can artificially activate those specific insula cells and observe any changes that happen in the body. We hope that studies like this will provide significant insights into how the brain and body communicate with each other.

Many studies show that a wide variety of mental and physical health conditions are associated with changes in the communication between our brain and our body [4]. We hope that the insights from our research, and that of many others, will contribute to the development of new treatments for diseases that affect the brain, the body, and the connection between them.

REFERENCES

1. Smith, G. P. 2000. Pavlov and integrative physiology. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* 279:R743–55. doi: 10.1152/ajpregu.2000.279.3.R743
2. de Araujo, I. E., Schatzker, M., and Small, D. M. 2020. Rethinking food reward. *Annu. Rev. Psychol.* 71:139–64. doi: 10.1146/annurev-psych-122216-011643
3. Barrett, L. F., and Simmons, W. K. 2015. Interoceptive predictions in the brain. *Nat. Rev. Neurosci*. 16:419–29. doi: 10.1038/nrn3950
4. Khalsa, S. S., Adolphs, R., Cameron, O. G., Critchley, H. D., Davenport, P. W., Feinstein, J. S., et al. 2018. Interoception and mental health: a roadmap. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* 3:501–13. doi: 10.1016/j.bpsc.2017.12.004
5. Livneh, Y., Ramesh, R. N., Burgess, C. R., Levandowski, K. M., Madara, J. C., Fenselau, H., et al. 2017 Homeostatic circuits selectively gate food cue responses in insular cortex. *Nature*. 546:611–6. doi: 10.1038/nature22375
6. Livneh, Y., Sugden, A. U., Madara, J. C., Essner, R. A., Flores, V. I., Sugden, L. A. 2020. Estimation of current and future physiological states in insular cortex. *Neuron*. 105:1094–111.e10. doi: 10.1016/j.neuron.2019.12.027

SUBMITTED: 01 February 2022; **ACCEPTED:** 26 April 2022;
PUBLISHED ONLINE: 20 May 2022.

EDITOR: Idan Segev, Hebrew University of Jerusalem, Israel

SCIENCE MENTOR: Yachel Baker

CITATION: Livneh Y (2022) How Does the Brain Connect the World Around Us to the World Inside Us? Front. Young Minds 10:867981. doi: 10.3389/frym.2022.867981

CONFLICT OF INTEREST: The author declares 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 REVIEWER

HILLEL, AGE: 12
I am 12 years old, studying in a gifted class that combines art and science. I won the National Math Olympiad, and I also participate in the Da Vinci program at Tel Aviv University. The piano has been with me from a young age—I compose, play and sing in a musical ensemble. Dogs are my huge love. About 2 months ago I experienced the loss of Kenny, a dog that was like my brother. He has been sleeping in my heart ever since. My first review is dedicated to the memory of my beloved dog.

AUTHOR

YOAV LIVNEH
I am the head of a research group in the Department of Brain Sciences at the Weizmann Institute of Science in Israel. My students and I explore how the brain interprets signals from our body, and how the brain affects bodily function. In high school, I studied chemistry and music and planned to be a psychologist. While studying for an undergraduate degree at the Hebrew University of Jerusalem, I became very interested in questions of how the mind and body interact. Along the way, I fell in love with biology, and especially with the biology of the brain. Today I am a researcher in that field. Around the same time, I also fell in love with my future wife, Daphna Nachmani, who is now a biologist and head of a research group at the Hebrew University of Jerusalem. We raise our children together with great curiosity and love. *yoav.livneh@weizmann.ac.il