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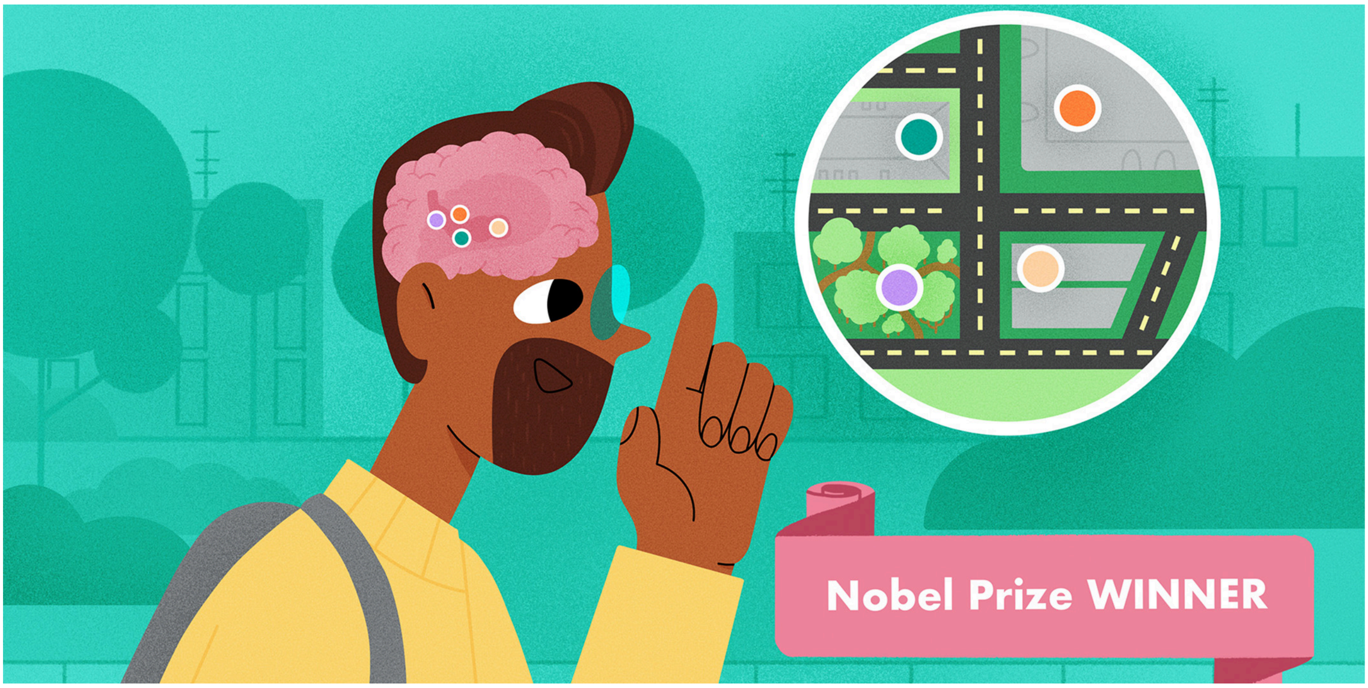

PLACE CELLS: THE BRAIN CELLS THAT HELP US NAVIGATE THE WORLD

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YOUNG REVIEWERS:


GEORG
AGE: 12


SUYANG
AGE: 15

Navigation through the space around us is one of the most fundamental and crucial abilities that humans and other animals have. This ability is so natural that we usually do it easily, without even thinking about it. Though finding our way through our environments seems effortless, it actually requires a complex, fascinating mechanism—the navigation system in the brain. In this article, we will explore a major group of cells that are part of this navigation system, called place cells. As you read, you will discover how the trait of curiosity helps the brain's navigation system, and you will learn some important lessons from taxi drivers in London!

Professor John O'Keefe won the Nobel Prize in Physiology or Medicine 2014, jointly with Prof. May-Britt Moser and Prof. Edvard Moser, for the discovery of cells that constitute a positioning system in the brain.

When you think about navigating from one point to another, what is the first thing that comes to mind? Is it the GPS system in your smartphone? Or maybe the field map that you got during your last trip with the scouts? Well, if you think about it, navigation is something that you do all the time—even when you take your dog out for a walk or stroll down the street to buy your favorite treat from the local grocery. Your brain uses its navigation system even if you are not moving your own body, but rather driving in a bus, a train, or a car. Have you ever wondered how this internal navigation system works? How do people recognize specific places, and how do we get from one place to another?

ROUTES VERSUS MAPS

The first principle we should be aware of before talking about the brain's navigation system is the difference between routes and maps. A specific *route* usually refers to one pathway that connects a person's current location with some other relevant location. You can think about a route as a set of instructions that leads a person to a desired place, using landmarks. For example, you might know that if you walk down your street, turn left at the first corner, and then turn right near the local Starbucks coffee, you will arrive at the grocery store. If you want to buy a treat in the grocery store, you can simply follow these instructions and landmarks, without needing to know the distance between your home and the grocery, or what other streets and shops are around.

But what would happen if the end of your street was blocked by construction work? Or what if the Starbucks was replaced by a clothing shop? Would you still be able to get from your house to the grocery, if you only knew how to follow the set of instructions described above? The answer is no, you would need a map to get to the grocery under the new conditions. This is key to understanding the brain's navigation system. As you now understand from the grocery example, to successfully navigate through the world, your brain must have an *internal representation* of the relevant locations, as well as of the relationships between those places. This representation, which forms a **mental map** of your environment, allows you to navigate in the world in a flexible way—in which you can use many routes to reach the same location. This flexibility is so important that animals frequently choose to navigate through different routes over simply using the less demanding method of following one known route. In other words, mental maps are the preferred strategy used by the brains of animals to enable them to navigate through the space around them.

MENTAL MAP

A representation of places in the world and their relationships to each other, which is constructed in the brain as an animal explores its environment.

PLACE CELLS

Nerve cells in the brain that help construct a mental map. They are located in the hippocampus and become active when an animal is in a specific location in its environment.

PLACE CELLS

This mental map of locations in the environment is formed in the brain using special cells called **place cells** [1]. Place cells are found in a brain area called the **hippocampus** (Figure 1A). It turns out that each place cell responds to a specific location in the world. This means that, when an animal roams around, a specific place cell becomes active when the animal is located in a specific location in space (Figure 1B).

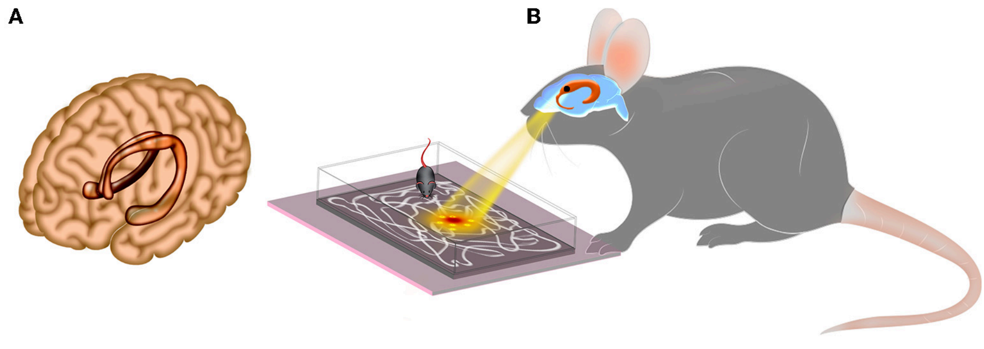

Figure 1

Here is a real-life example to demonstrate how the activity of place cells creates a map in the brain. When you walk around a specific place in your neighborhood, for example in the park near your home, a certain group of place cells becomes active, with the activity of each cell based on your specific location in the park. When you walk around in other place in your neighborhood, say your school yard, another group of place cells becomes active, each cell at a different location in the yard (Figure 2A). This activity of place cells in your hippocampus enables you to create a mental map of your neighborhood (Figure 2B) [2].

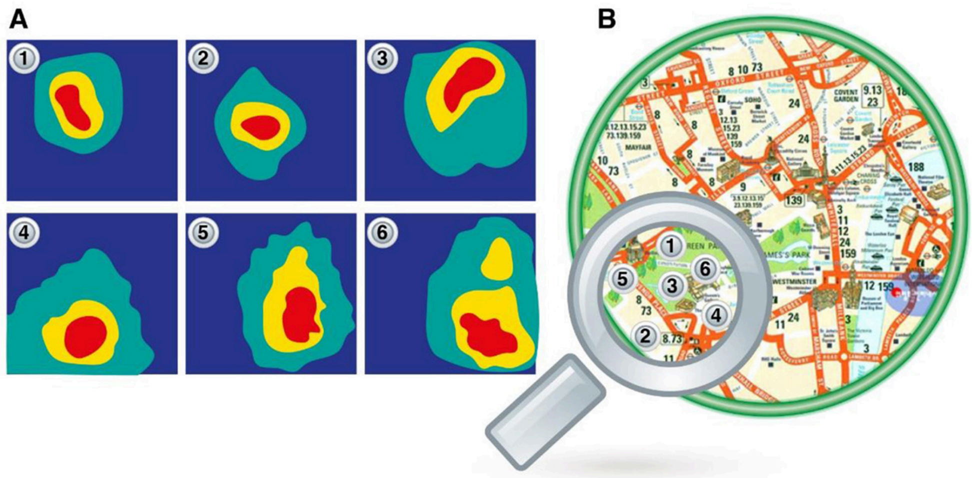

Figure 2

HIPPOCAMPUS

A seahorse-shaped area deep in the middle part of the brain, between the ears. It contains an important part of the brain's navigation system, in the form of place cells.

Figure 1

Place cells in the hippocampus. **(A)** The hippocampus is a seahorse-shaped region located deep in the middle of the brain (orange). It contains (among other cell types) nerve cells called place cells, which are fundamental for navigation. **(B)** When an animal moves in the space around it (gray lines in the box), a specific place cell in its hippocampus (black dot in the mouse's hippocampus) becomes electrically active when the animal is in a specific location in the environment (orange spot in the box). This cellular activity helps the animal to build a mental map of the environment, allowing it to flexibly navigate in the world (Image credit: https://medicalxpress.com/news/2015-10-role-hippocampus-memory.html and https://www.nobelprize.org/uploads/2018/06/advanced-medicineprize2014.pdf).

Figure 2

Place cells form internal maps in the brain. **(A)** An example of the activity of six individual place cells **(1–6)**. The location in the environment where each cell is most active is represented by the red area. Yellow and green areas represent minor activity, and blue represents no activity. Each cell is most active in a specific location in the square, which corresponds to a specific location in the environment. When taken together, the fields of all active cells cover the entire surface of the environment. **(B)** The collective activity of the place cells in a given environment creates a mental map of this environment in the brain (Image adapted from https://www.nobelprize.org/uploads/2018/06/okeefe-lecture.pdf).

WHAT CAN TAXI DRIVERS TEACH US ABOUT THE HIPPOCAMPUS?

Twenty years ago, before the age of smartphones equipped with GPS, people navigated using their own memories. One population that used navigation skills more often than others was taxi drivers! Back then, taxi drivers drove their passengers from one place to another in the most efficient way, based on their mental maps of the city and their experience with traffic conditions at certain times of the day. A study performed in 2000, showed that a specific part of the hippocampus in taxi drivers in London was larger than that of people who did *not* navigate as extensively through the city [3]. This was important evidence showing that the hippocampus is part of the brain's navigation system. It was further shown that the hippocampi of taxi drivers remained larger only as long as the drivers kept navigating from memory. This brain area shrunk back to normal size if drivers stopped this activity.

CURIOSITY HELPS ANIMALS TO FORM MENTAL MAPS

Now that we know that the brain forms an internal map of the environment around us using place cells, let us think about the construction of this internal map from a different angle. To construct a map of the environment, an animal must move around and explore various regions of its environment. However, what would motivate the animal to do so? You might think that the animal would be motivated by hunger or thirst, but it turns out that animals explore their environments *even more* when they are not hungry or thirsty (Figure 3) [4]!

So, what else, besides hunger or thirst, could motivate an animal to move around in its environment? Here is a hint: what do you feel when you arrive in a new place? You probably guessed it—you experience *curiosity*! Curiosity is a very strong motivator, and it prompts animals to move around in their environments. In other words, curiosity is part of our nature as animals, and it is part of the system of building mental maps. Scientists believe that curiosity was formed by evolution, to drive us to explore our environments so that we could build mental maps of them—which helps us to successfully navigate in the world. If you think about it, it is curiosity that motivates us to acquire *any* new information, so it is interesting to wonder whether this ancient evolutionary impulse to navigate our environments also eventually led us to be interested in (and curious about) our favorite hobbies, skills, or crafts!

Figure 3

Figure 3

Animals form internal maps by exploring nature. When animals arrive in a new environment, they explore that environment out of curiosity. So, curiosity allows an animal to form a mental map of its environment.

MENTAL SPACE OR PHYSICAL SPACE?

Let us consider an interesting and complex philosophical puzzle: do we build our mental representations of space based our environments *as they actually are* in the outside world, or do we *create* the characteristics of physical space based on a mental model of space that we are born with?

Personally, I support the second option, which lines up with the ideas of the famous philosopher Immanuel Kant and the psychologist Edward Tolman. According to this approach, we are born with a set of brain structures that organize the world for us in a very specific and elementary way, so that we can make sense of the information we perceive about the world through our senses. In other words, the brain is organized and built to experience the world in a certain way; it uses a specific "lens" or "window" through which we perceive the world as we do. This approach means that we perceive space in a particular way because our brains are built in a particular way—not because the outside world, by itself, is inherently structured the way we perceive it. I admit that this is a hard concept to grasp, so take your time, think about it, and see where it leads you.

RECOMMENDATIONS FOR YOUNG MINDS

Brain-Inspired Recommendations for Life Decisions

I want to tell you a personal story and share some insights generated from our current understanding of the brain. I did very poorly in high school, so, when I was 18 years old, I had to think about my future and decide whether to accept that I was a failure. I decided that I had to take responsibility for constructing my own personality and my own life, and that I could not blame my failure on the world. I advise you to do this as well—and to understand that the brain is a very active organ. We spend a lot of time deciding what to do, what information to take in, how to handle that information, and how to interpret it. That means that we can take responsibility for, and control over, many of our actions—and their results.

Additionally, inspired by the navigation system in the brain, I believe that you should look at yourself and your situation and try to plan where you want to be—which might not necessarily match where you are now. You can use the brain's navigation system as a metaphor for finding your way through life. When you are at a particular location in your life trajectory, try to decide which direction you want to go. You may not get there—you may find that there are all kinds of roadblocks—but this is still a good way of organizing your life and making decisions. Remember that many routes can lead to the same destination! So be flexible, especially when you come across obstacles that divert you from your original route.

How to Enjoy Science

To be a good scientist, you must have a certain objective view of the world, and you must be prepared to change your mind according to the evidence. Science is not for everybody, because some people do not enjoy the uncertainty of dealing with unexpected truths. But for those who enjoy this type of journey, being a scientist is one of the most rewarding, exciting, and fulfilling careers that I know of (Figure 4). It is like living in a never-ending detective story, one in which every time you solve one mystery, a whole bunch of other interesting problems appear!

The trick is to pick an important area of science and a problem within that area that is solvable with the available tools—or a problem for which you can invent *new* tools that might make it solvable. Then, occasionally, you will be rewarded by the thrill of realizing that you discovered something important about how the world works—something that could influence a lot of people's ideas and perhaps even their lives. This sort of influence certainly is one of the ingredients of a successful and happy life.

Figure 4

Figure 4

Enjoying science. To be a good scientist, you must enjoy journeying in uncertainty, encountering unexpected truths, and changing your mind according to the evidence. Not everyone enjoys this type of journey, but those who do can truly enjoy a career in science. It is one of the most rewarding, exciting, and fulfilling careers available!

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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 REVIEWERS

GEORG, AGE: 12

I am Georg, I like hanging out with my friends, riding my bike and playing sports, especially basketball. I also like natural and technical sciences. I am interested in understanding how things are built and repairing what has been accidentally broken. This is convenient when you consider that as a child, I was much busier breaking what was in my surroundings. So, now I can keep myself busy! I hope you will enjoy this manuscript as much as I did!

SUYANG, AGE: 15

Hello, I am a current 10th grader. I have been involved in several science and speech competitions, and I have been swimming for 10 years and I love it! I also love reading books (mostly science books and biographies), and my favorite historical character is the Chinese poet Sushi (Su Dongpo). I am interested in pursuing a career in either Engineering, or Medicine, or AI. I am excited to be a reviewer for Frontiers for Young Minds.

AUTHORS

JOHN O'KEEFE

Prof. John O'Keefe is a British-American neuroscientist. Prof. O'Keefe earned his bachelor's degree at the City College of New York (USA), where he studied psychology and philosophy. During this period, he also studied filmmaking, advanced English literature, physics, psychology, and philosophy—and this is when he met his wife Eileen. During this time, he got a firsthand taste for experimental brain research, and he was hooked. He supported himself by working in the library, showing classic European films for various courses, and driving a taxicab in the evening. Prof. O'Keefe then went on to earn his master's and doctorate degrees in psychology at McGill University in Montreal (Canada), which was considered the Mecca for the study of physiological psychology. In 1967, Prof. O'Keefe joined University College London (London, UK) as a postdoctoral research fellow and he is still there, currently serving as a professor of cognitive neuroscience. During his years at University College London, Prof. O'Keefe studied the hippocampus using advanced brain recording techniques that monitored the electrical activity of individual neurons in the brains of rats. This research lead Prof. O'Keefe to the discovery of place cells, which are an important part of the navigation system in the brain. For this discovery, Prof. O'Keefe was awarded the Nobel Prize in Physiology or Medicine in 2014. Prof. O'Keefe won many other prestigious awards, including the Louisa Gross Horwitz Prize (2013), and the Kavli Prize in Neuroscience (2014). He is a fellow of the Royal Society. In 2016, he was elected to the National Academy of Sciences and, in 2019, he was admitted to the Royal Irish Academy as an honorary member. *j.okeefe@ucl.ac.uk