THE SENSORY HOMUNCULUS

ABSTRACT

Each hemisphere of the brain can be divided into specialized areas, one of which processes sensory information. This strip of the brain can be further broken down into areas that are responsible for interpreting sensations from specific parts of the body. The "sensory homunculus" is a useful visual representation depicting the relative number of cells in each of these regions. New relationships between the regions are formed when sensory information is missing. Here, we breakdown the history and meaning of "sensory homunculus" and discuss two studies that demonstrate how the model can change. The first study discussed demonstrates that unused brain regions can be "recycled" by surrounding regions. The second study shows that these changes can occur over the short time of twenty-four hours and can be reversible once normal sensory input is restored. Though developed in the 1950s, this model is still relevant today in guiding research studies in areas such as amputation recovery and epilepsy treatment.

FUNCTIONAL REGIONS OF THE BRAIN

Your brain is approximately a three pound mass of Jello-like consistency. Functionally, however, the brain is much more sophisticated. The outer layer of the brain, called the cortex, is wrinkly tissue made up of an estimated 80 billion tiny cells called neurons. Groups of nearby neurons make up specialized networks in the brain that communicate with the different parts of the body. Scientists in the first half of the 1900s used microscopy and electrical stimulation to divide the brain into unique regions that communicate with specific body parts. The model developed from their work, called the homunculus, is still used today to inform scientific studies and medical procedures.

THE ORIGIN STORY OF DIVIDING THE BRAIN

Dr. Korbinian Brodmann, a German neurologist, first discovered that the cortex could be broken down into regions in 1909 [1]. By studying thin slices of brain tissue that were "stained" under a microscope, he divided the brain into fifty-two distinct areas based on the cell types and structures of the layers. These anatomical regions are termed "Brodmann areas" and are still referenced today. Of note, Brodmann areas 1, 2, and 3 are more commonly known as the primary sensory cortex. The sensory cortex is responsible for interpreting sensory information from our limbs such as helping us to recognize the soft texture of a blanket as you run your hand across it or the sensation of a baseball leaving your hand as you throw it. Although Brodmann contributed to neuroscience by determining these special regions, he could not have used this technique in live patients to confirm the function of these areas.

Dr. Wilder Penfield was an American neurosurgeon who operated on epileptic patients whose condition could not be treated by medicine. Epileptic events, otherwise known as seizures, occur due to highly synchronous/abnormal brain activity. Sometimes the source of the abnormal brain activity is located in a very specific region in the brain. This can be removed to treat the disorder. In the 1950s, to determine the area of the brain he should remove, he sent a small amount of electricity into the brain of his conscious patients. When the electrical signal replicated the aura that occurs before an epileptic episode, he would know that was the portion of the brain to be removed. Interestingly, he also discovered that the electrical stimulation applied to a specific part of the somatosensory cortex would elicit physical sensations in a specific portion of the patient's body [2]. This finding was repeatable across patients: the same relative locations in each brain produced a sensation in the same location on the body. From this information, he developed the sensory homunculus.

ORGANIZATION OF THE SENSORY CORTEX AND THE SENSORY HOMUNCULUS

Interestingly, the areas of the brain that interpret sensations, known as the "sensory cortex", are organized in a way that resembles the relative distance of the appendages on the body. For instance, each one of our fingers corresponds to a small portion of the sensory cortex. The thumb portion of the sensory cortex is near the pointer finger portion of the sensory cortex, and the index finger region is closer to the pinky region of the sensory cortex. This pattern continues throughout the entire body. Towards the middle of the brain, there is an area for each foot's toes. From the middle outwards, there is the foot area, then the leg area and so on continuing up the body. Interestingly, the area responsible for sending signals to move or sensation is not proportional to the physical size of the body. If we build a human that represents what this would look like, we end up with this famous figure of neuroscience – the homunculus, which is Latin for "a humanoid creature." Here, appendages are represented in proportion to the number of neurons that represent that body part: the larger the region is, the more neurons the area has.

AT-HOME EXPERIMENT

This can be tested by doing a quick experiment with an adult. Have the adult unravel a paper clip so that there are two pointed ends about a quarter inch apart from each other. Close your eyes and let them randomly poke you with either one or two points, and see if you can sense how many points they are touching you with. Try on a sensitive area first: the fingers. Then, compare your performance on a less sensitive area: the upper arm. You'll notice that your accuracy is much better for the fingers because they have more neurons to represent each one in the brain.

USE IT OR RECYCLE IT

The size of each area is not the same throughout life. The brain is constantly changing and making new connections. When no sensory input exists for an extended period of time, the brain undergoes changes. Instead of "throwing out" the area of the brain that is no longer used, the brain recycles the neurons present. One extreme event that causes changes is after loss of a limb. For example, in patients who have lost their arms, the areas of the brain representing the arm are taken over by adjacent regions. In one study by Merzenich and colleagues [3], the researchers studied the brains of adult owl monkeys who had lost their middle finger. By providing small electrical currents to the fingertips, they determined the size of the area of the brain in the sensory cortex that represented each of the five fingers before and after the surgery. They discovered that, without the middle finger, the corresponding area of the brain shrunk. The adjacent fingers – the pointer finger and index finger – invaded the area of the brain that previously represented the middle finger. In other words, the area of the brain that represented the pointer and index fingers grew by "recycling" or forming new networks with what was not being used to control the missing finger.

FAST AND REVERSIBLE CHANGES

Thankfully, scientists can study brain activity without opening the skull. In one study by Kolasinski and colleagues [4], a group of researchers used an imaging technique called functional magnetic resonance imaging (fMRI) on humans. Doctors routinely use MRI to take static scans of brain regions to look for abnormalities such as tumors and ruptured blood vessels. Functional MRI, however, enables scientists and doctors to view brain activity in real time. In a research study, they investigated the areas of the sensory cortex related to each finger. Using fMRI, they could distinguish signals that belonged to each individual finger, similarly to the results of the monkey study. Their research did not stop there, though. They wanted to study how humans can change the size of each region over the course of just one day. To do this, they glued the right index finger to the right middle finger using surgical-grade super glue.

Due to the hand's anatomy, moving the middle finger without moving the ring finger is difficult. Try it yourself: stretch out your fingers and try moving your middle finger up and down while keeping the rest of your fingers in place. You will probably find that you are unable to move the middle finger without moving your ring finger. This behavior is also physically represented in the brain. The area of activity of the two finger regions overlap. In this fMRI study, however, the researchers demonstrated that, after the middle and ring fingers had been separated during the gluing period, the ring finger area had more activity towards the edge of the region touching the pinky area than the middle finger area. The effect of this change was apparent in a study in which the subjects, once their fingers had been unglued, had to rapidly tap the finger indicated on a computer screen. The subjects confused their ring finger with their pinky finger more than with the middle finger. These researchers were able to demonstrate that reorganization of brain networks can occur on the timescale of one day and causes temporary changes in the subjects' behavior.

SUMMARY

The brain contains a map of the body's limbs in the sensory cortex. The homunculus is a useful visual representation depicting the relative number of neurons between the sensory areas. This model is not stationary throughout your life, however. New relationships or "networks" can be formed when external environmental inputs are either permanently or temporarily removed. The first study demonstrated that if sensory information was permanently deprived to a limb, the remaining limb regions in the brain "recycle" the unused area. The second study showed that these changes can occur over the course of just twenty-four hours and can be reversible once normal sensory input is restored. Studying this model is important because it allows scientists, engineers, and doctors to better understand how the human brain reorganizes itself and to develop new solutions to help those with disorders such as epilepsy and missing limbs.

References

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