Brain health: a guide for patients

Introduction

As I sit here writing on this computer keyboard, it occurs to me that having a healthy brain means that one is entirely unaware of its functioning whatsoever. My computer functions without me having to understand the mechanism of the keyboard, the word processing software that generates text on the screen from the keystrokes, the operating system that runs in binary in the background, and the highly advanced silicon processors and integrated circuit boards that comprise the computer hardware. Of course, I very quickly become aware of the inner workings of a computer – the software, operating system, or hardware – if the screen won't turn on, my documents won't open, or if I drop the computer and it breaks into pieces.

This computer analogy for the brain is accurate enough. In my estimation the brain is millions or greater times more complex than a modern computer, but the principles are the same. When the brain is functioning well it is entirely in the background, humming along just like our computer does. We can think of times when we are enjoying ourselves, enjoying dinner with family or friends, watching a moving or a sports event, or meditating or enjoying a massage – there is no thought of the functioning of circuits of the brain. When participating in an activity of high dexterity or complexity, such as riding a bicycle in a new place while holding a conversation with a friend, our brain is simultaneously activating circuits involving muscle control, balance, sensory control, language, vision, emotion and socialization. No computer could match the ability of the brain to carry out so many complex tasks with such flexibility, and I have doubts that computer science will ever be able to match the computational ability of the brain across so many domains in an organ that weighs only 3 pounds!

On the other hand, this manuscript is written for people who notice their brain isn't working quite right or when its functions become apparent to us. Rather than having a brain that is humming along in the background, serving the complex aspects of daily life, the "software, operating system, and hardware" the inner workings of brain become of interest to us. In the following pages, I will attempt to address these questions:

- How does a well-functioning brain work? What can we learn from those who have maximized their brain capacity?
- What is the structure of the brain?
- What are the tools for measuring the functioning of the brain, and when do we know when it isn't working properly?
- What are the conditions and diagnoses that can affect brain functioning? How can we treat these conditions?
- What are other interventions, including nutritional supplements, exercises, brain training, and other lifestyle changes that can maximize our brain health as we go through life?

Our brains, evolved over time

Perhaps the most remarkable feature of the brain is its flexibility and ability to adjust to a wide range of situations. Other animals are specialists: the cheetah's speed to run down certain animals, the giraffe's size matching the height of acacia trees, or most other creatures in the sea, land or air that have evolved to their particular environments.

It is understood that the human brain evolved to its current form approximately 30-100,000 years ago and has not significantly changed since (Neubauer). At that point, small groups of humans had moved beyond Africa to Southeast Asia and Europe and are thought to have been living in small family and nomadic groups. At this point the neural circuits responsible for language, movement, social interactions and emotion had slowly evolved over a million years into their contemporary forms (Robson). Evolutionary developments included an increase in the number of neurons (estimated at 85 billion or more) and increasing complexity within the molecular and microscopic wiring of the brain (Verendeev, Lui).

Next, an "explosion" of human achievement has been identified starting approximately 30,000 years ago based on the development of religion and ritual, painting and other arts, and signs of social hierarchy, and this progression continues through the current day. This explosion was based on two major developments in functional capacity (Gabora). One development is that humans developed the ability to build upon previous generations' knowledge, a process known as "ratcheting up." Another major evolutionary step was that the brain developed that capacity to be uniquely shaped the environment instead of having hard wired innate functions present at birth as many animals do. The frontal lobe circuits discussed in the following pages allow for the extreme flexibility allowing humans to master different scenarios and to learn from previous generations.

Consider the ways that humans have developed since our humble beginnings using nothing more than the brain developed those millennia ago:

- Colonization of the entire planet and its varied environments; even traveling to space or deep below the ocean's surface
- The development of complex societies with individuals playing specific roles to support the collective society
- Individuals honing their skills and minds for particular pursuits such as mastering chess, developing artistic talents, or mastering physical or sporting challenges
- Development of thousands of widely varying languages, cultures
- The development of science and knowledge based on centuries of cumulative experience

Keeping our brain evolution in mind is important. *We need to understand both the limitations resulting from our brain's archaic evolutionary past as well as our brain's innate flexibility to meet challenges in front of us.*

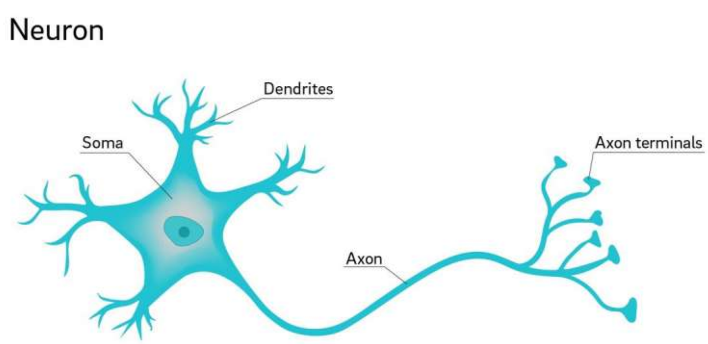
Our brains, structure and function

The basics of the structure and general functioning of the brain are fairly straightforward and vital for understanding when a question of dysfunction occurs. Our brains consist of circuits of neurons that take in information from the outside world, operate internally, and generate our behaviors and movements in the world. The neuron and other cells within the brain are themselves “little worlds,” each comprised of proteins, DNA, and neurotransmitters that serve as the means of communication between neurons and within the neuronal circuits.

A poorly kept secret about our brain anatomy, structure, and function is that far more is *not* known about the brain than has been discovered. We scarcely understand how DNA encodes the information that runs our cells, proteins are folded, cells operate internally, how the connections (known as synapses) between cells work, and how the circuits of the brain operate separately or together. However, from decades of efforts and thousands of research labs focused on these matters, we have gained glimpses into the functioning of our brains’ circuits and the cells that comprise these circuits. This section will attempt to give a five-minute overview of the neurosciences.

The brain’s computational circuitry

The “brain as computer” is a familiar concept. Just as our computer uses electrons flowing through silicon processors to represent digital information, our brain represents information using electrical activity generated within neurons, flowing through axons (the neuron’s wiring), and joining with other neurons at synapses within the axon terminals where neurotransmitters stimulate the next neuron to fire. The complexity is staggering: we are estimated to have 100 billion neurons and 100 trillion synapses. Whereas computers utilize transistors that take in predigested digital data, our brain process more complex analog and digital inputs from the environment and are estimated to be millions to billions more powerful than contemporary computers with most real world tasks.



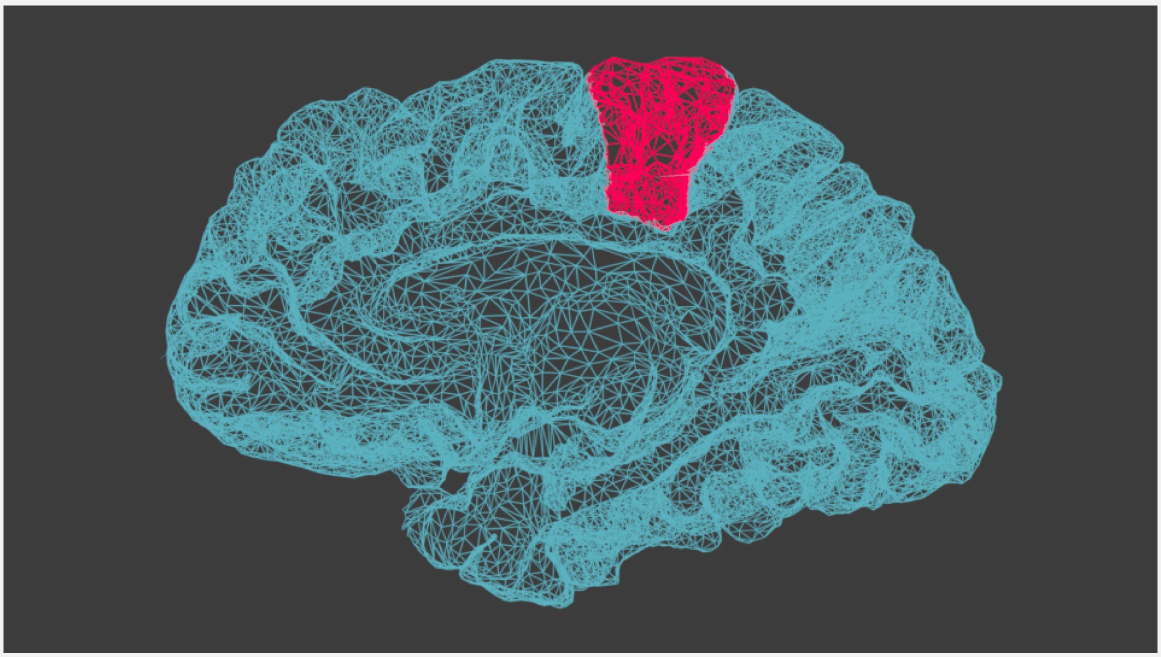
Neuron model. Input travels via dendrites to the neuron soma/cell body, and action potentials to the next neuron travel via the axon, to the axon terminals, and via synapses to the next neuron.

The brain is modular in many ways; there a number of circuits that serve particular functions: vision, language, movement, sensation, emotional control, memory. Neurologists can predict the location of a brain hemorrhage or tumor based on particular symptoms, for example the loss of ability to understand speech predicts a problem with functioning of the left posterior part of the brain.

Creativity: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3313946/

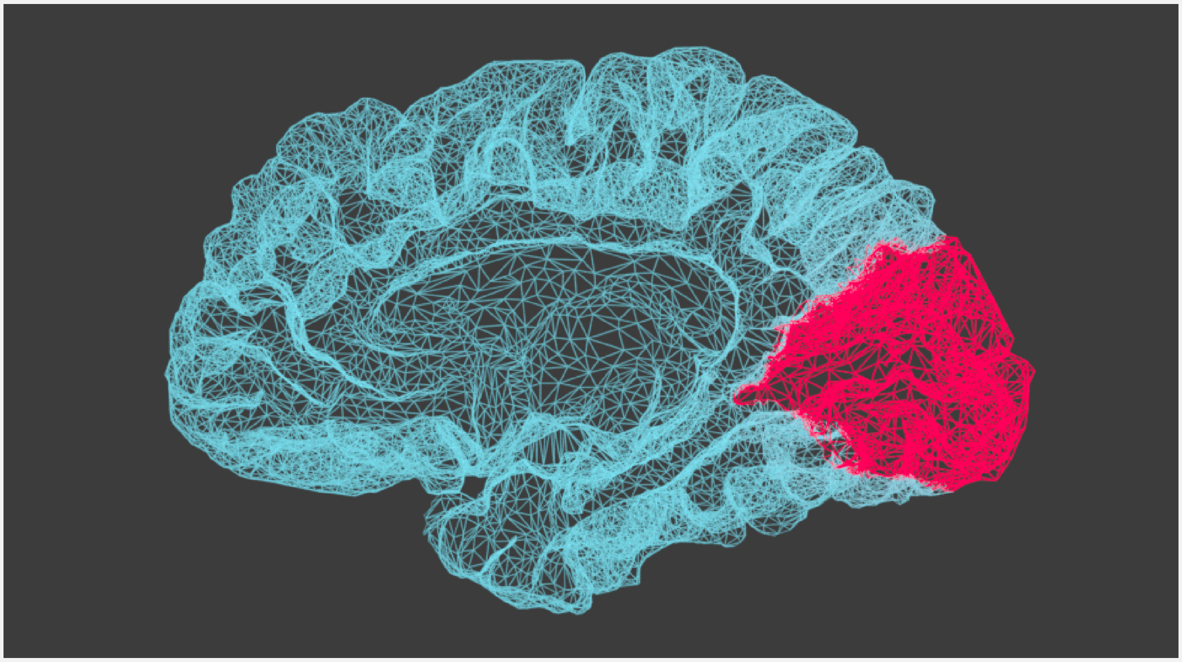
Motor circuit

Muscle activation and movement is generated by the posterior frontal lobe (shown in red) by neurons that travel through the brainstem and spinal cord. Complex movements requiring the coordination of multiple muscles, throwing a ball, for example, is controlled by the premotor cortex (shown in blue). Balance and stability additionally involve fine motor control neurons in the cerebellum and deep brain structures.



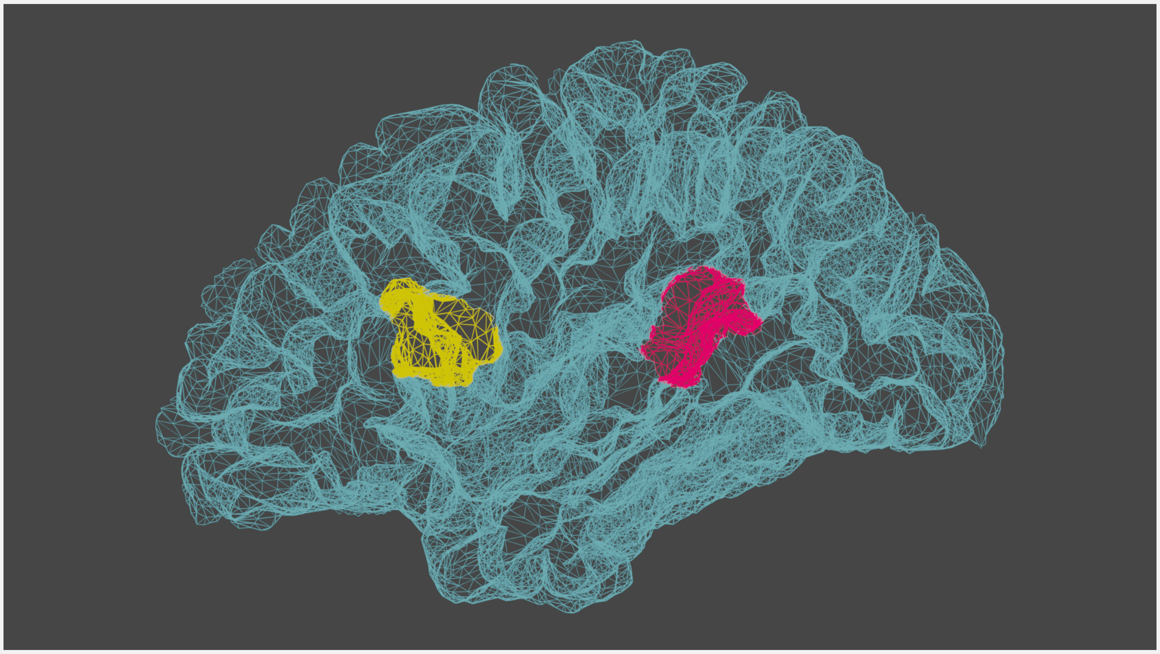
Visual circuit

Visual input travels from the retinas, through the optic nerves, and into the visual cortex in the occipital lobe at the posterior part of the brain (shown in red). Neurons within the occipital cortex reconstruct the visual information to be used by portions of the brain responsible for navigating the environment, reading, recognizing faces, or other functions requiring visual input.



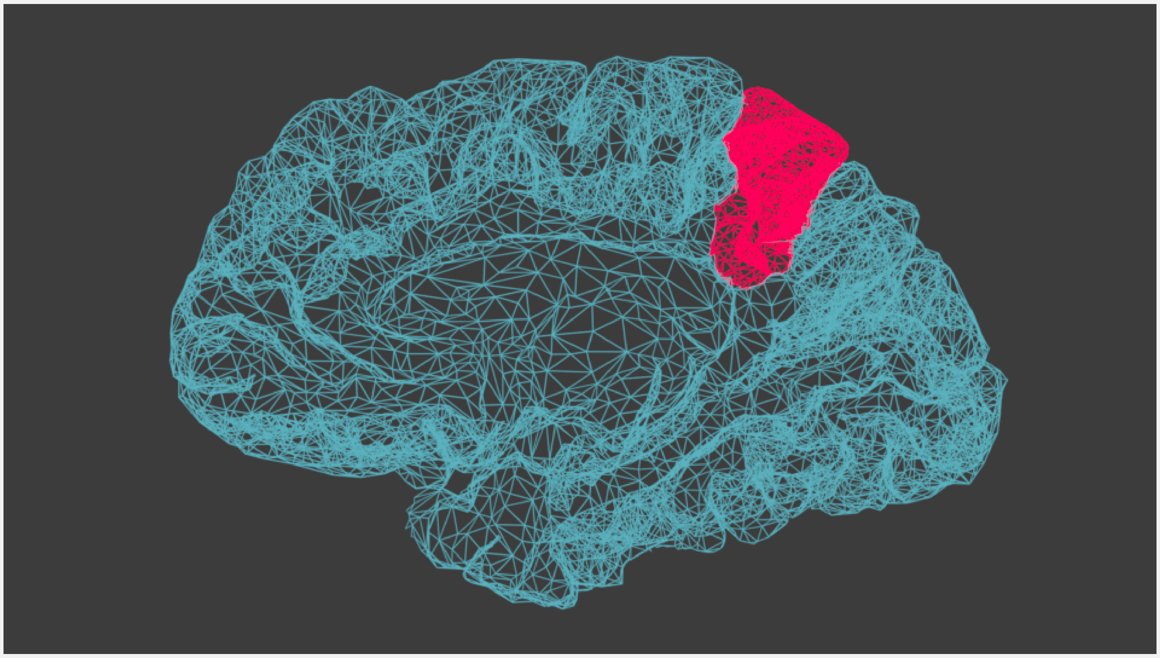
Language circuit

Auditory input arrives from the ears and brainstem into neurons in the temporal lobes at the sides of the brain. The comprehension of language is localized to left hemisphere of the brain for right-handed people and half of left-handers in a region of the brain known as Wernicke's area (red). A fiber tract reaches from Wernicke's area to Broca's area (in blue) in the frontal lobe where speech production occurs.



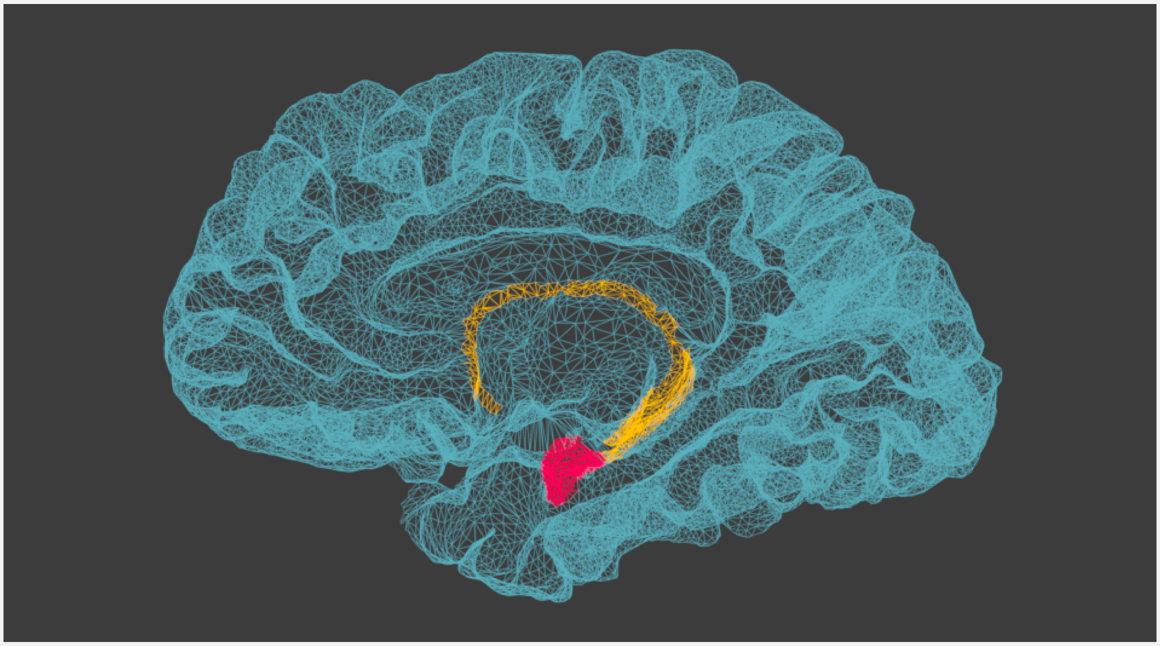
Sensory circuit

Sensory input arrives from the body via the brainstem in in the parietal lobe in the sensory cortex (in red). The brain generates a three-dimensional map of the body in the world in visuospatial cortex (in blue) with association with brain regions involving sensation and vision.



Memory circuit

New memories are generated via a deep temporal lobe structure called the hippocampus (in red) and through a circuit that runs throughout the brain. Memories are stored throughout the brain in a distributed manner: the verbal aspects of a memory are based on the activation of language circuit neurons and so on.



Frontal cortex

The frontal lobe is the “master control” for the rest of the brain and regulate mood, attention, focus, decisions, socialization, and decision making in general (Henri-Bhargava). Its circuits are complex in comparison to the more straightforward circuits described previously.

The **superior medial prefrontal cortex**, shown in red, and deep brain structures which modulate its function (in blue), are responsible for motivation, energy levels, and the ability to carry out activities efficiently. If a patient suffers from damage or dysfunction to this structure, apathy and poor motivation is the result.

The **lateral prefrontal cortex**, shown in red, is responsible for executive function, including working memory, task setting, and monitoring one’s own performance. Difficulty with carrying out complex tasks such as planning for a vacation or balancing a checkbook can result if a patient suffers from damage or dysfunction to this structure.

The **orbitofrontal cortex**, describing the brain region directly behind the eyes, shown in red, is responsible for emotional regulation social cognition (Firat), and regulating impulsive behaviors. If a patient suffers from damage or dysfunction to this structure, inappropriate behaviors, personality changes and a loss of appropriate socialization is expected.

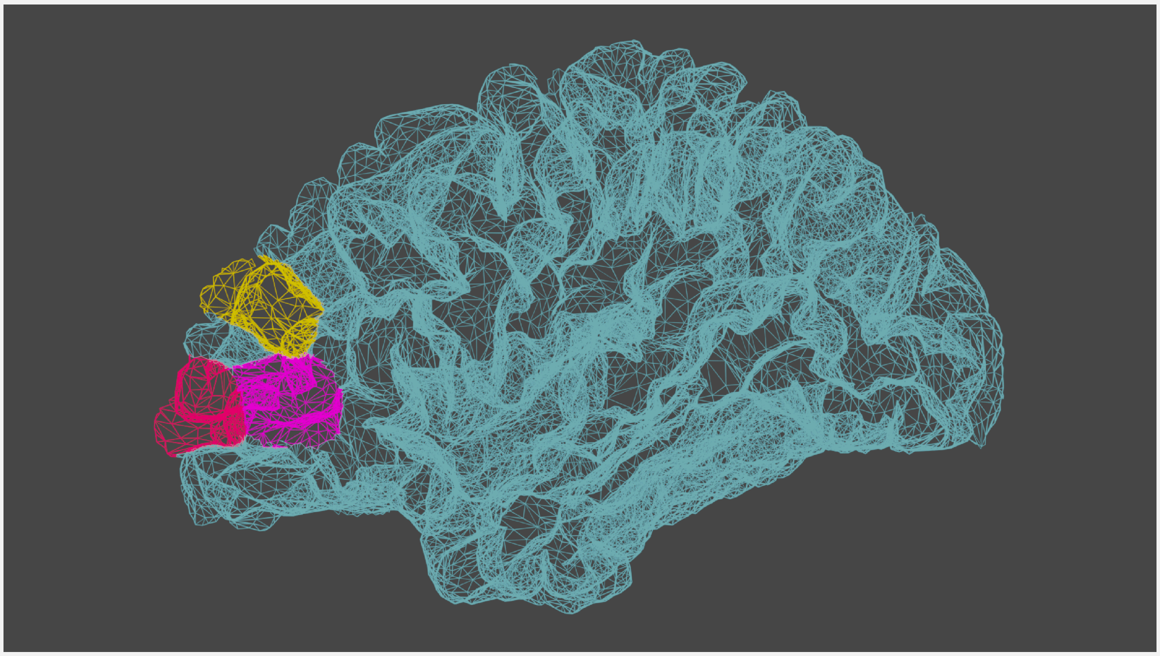
The **dorsolateratal prefrontal cortex**, shown in red, is considered a “master regulator” of other circuits within the prefrontal cortex and has been shown to have abnormal functioning in patients with depression. If a patient suffers from damage or dysfunction to this structure, mood impairment can be anticipated. This structure is the typical target for transcranial magnetic stimulation.

The **cingulum**, shown in red, serves to connect and regulate information traveling between the deeper brain structures that are involved with emotion and physical states of the body such as pain in addition to regulation of memory. Impairment in memory and emotional functioning can be expected if a patient suffers from damage or dysfunction to the cingulum.

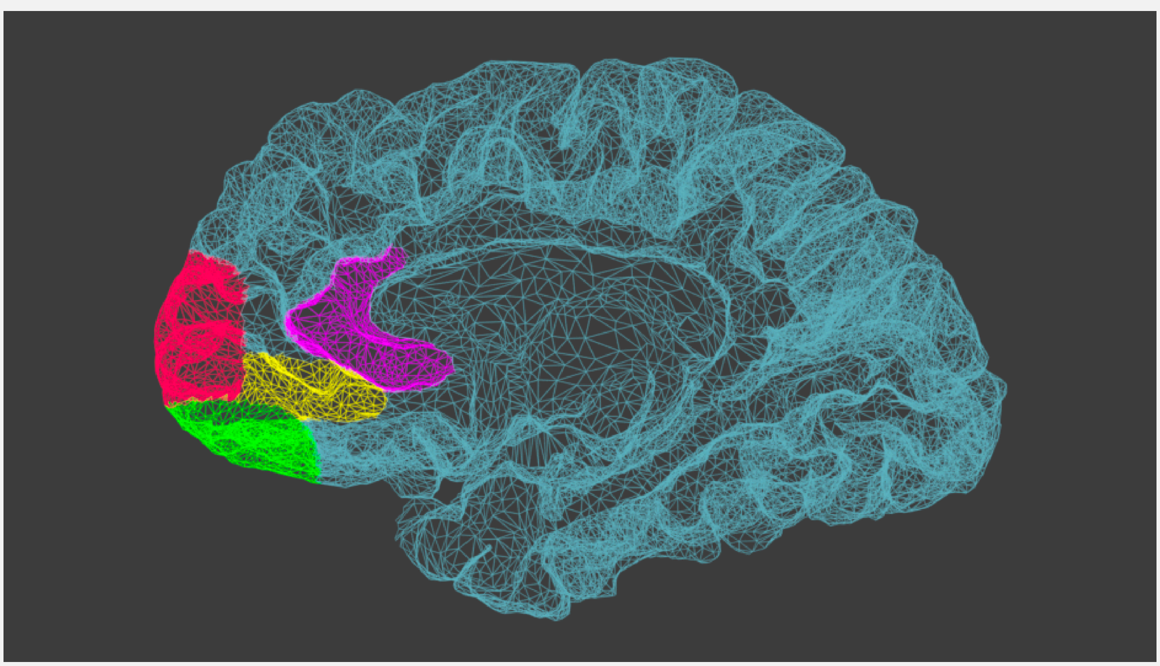
The **frontal pole**, describing the most anterior frontal region, shown in red, is responsible for the highest levels of cognition, including understanding our own and others’ states of mind, empathy, and integrating multiple thought processes simultaneously.

Frontal cortex anatomy

Lateral frontal lobe. Frontal pole in red, dorsolateral prefrontal cortex in yellow, lateral prefrontal cortex in purple.



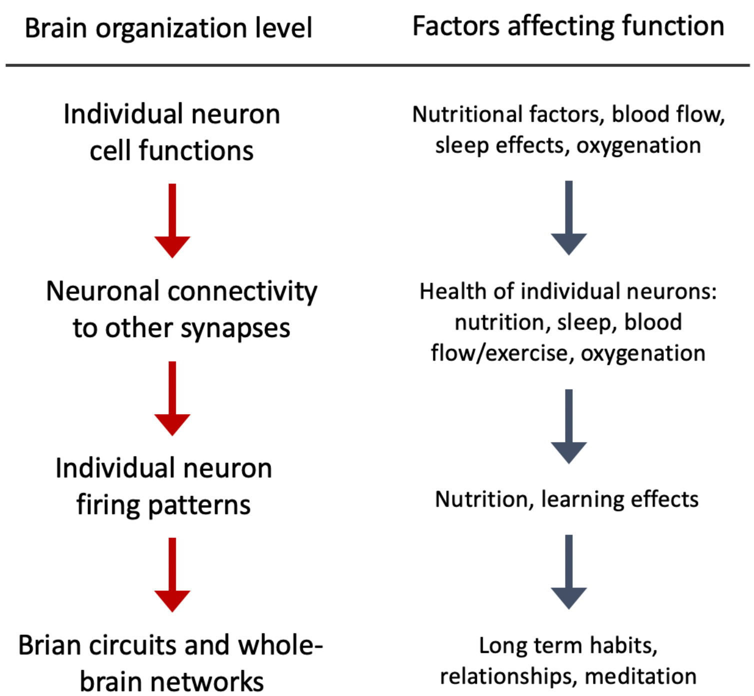
Medial frontal lobe. Frontal pole in red, orbitofrontal cortex in green, cingulum cortex in purple, superior medial prefrontal cortex in yellow.



As if the above described circuits were not sufficiently complicated, we also must factor in the firing patterns of neurons within these circuits. As mentioned above, each neuron has inputs from other neurons at the synapse, and based on the inputs from these synapses, the neuron will fire an action potential down its axon towards the synapse of another neuron. Synapses can be straightforward, with 5-10 input neurons, or complex, as in the motor neuron, with thousands of inputs from different neurons located nearby or distantly (Lerner). Based on those thousands of inputs the motor neuron will fire a potential, leading to muscle movement. The inputs are adjusted in intensity by support cells called glial cells, and at this point we have not identified all of the types of cells and have only the most basic understanding of the makeup of even the most studied neuronal circuits, such as the basal ganglia circuit affected in Parkinson's disease.

Neuronal circuits are firing continuously, generating activity that can be detected by scalp electrodes via EEG or functional MRI scans. Neuronal firing within a circuit typically occurs at 200-1000 hertz (200-1000 activations per second), whether at rest or if the circuit is activated. The scarcely understood changes in the patterns of these circuit activation patterns generate our sensory experiences, behaviors, and the basic frontal lobe functions that make us human.

Finally, the activity and function of individual neuronal and glial support cells deserve attention**. Each individual neuronal cell has the ability of firing an action potential every 1-10 seconds, and the mechanics of doing so is staggering: each cell is a universe in miniature. Each neuron carries the DNA encoding its protein and functions, organelles to generate proper cell functioning, scaffolding to build the proper shape to connect to distant synapses, and neurotransmitter delivery to allow for proper synaptic communication. Intensive research continues into the role of nutrition to support cell function as well as a basic understanding of each aspect of normal neuron functioning.**



Brain organization and factors affecting each level of functioning.