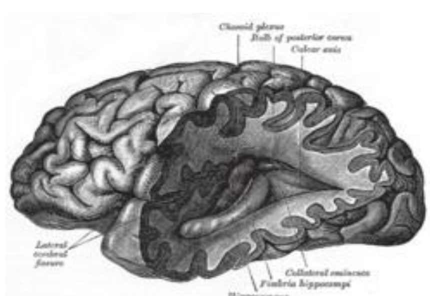
NEUROSCIENCE

1. NEUROSCIENCE: HISTORY & MODERN ADVANCES

1.1. Foundational Knowledge & History

Neuroscience is the scientific study of the nervous system. Traditionally, neuroscience has been seen as a branch of biology. However, it is currently an interdisciplinary science that collaborates with other fields such as chemistry, computer science, engineering, linguistics, mathematics, medicine and the allied disciplines of philosophy, physics, and psychology. It also exerts influence on other fields, such as neuroeducation and neurolaw. The term neurobiology is usually used interchangeably with the term neuroscience, although the former refers specifically to the biology of the nervous system, whereas the latter refers to the entire science of the nervous system.

The scope of neuroscience has broadened to include different approaches used to study the molecular, cellular, developmental, structural, functional, evolutionary, computational, and medical aspects of the nervous system. The techniques used by neuroscientists have also expanded enormously, from molecular and cellular studies of individual nerve cells to imaging of sensory and motor tasks in the brain. Recent theoretical advances in neuroscience have also been aided by the study of neural networks. Because of the increasing number of scientists who study the nervous system, several prominent neuroscience organizations have been formed to provide a forum to all neuroscientists and educators. For example, the International Brain Research Organization was founded in 1960, the International Society for Neurochemistry in 1963, the European Brain and Behavior Society in 1968, and the Society for Neuroscience in 1969.



The study of the nervous system dates back to ancient Egypt. Evidence of trepanation, the surgical practice of either drilling or scraping a hole into the skull with the purpose of curing headaches or mental disorders or relieving cranial pressure, being performed on patients dates back to Neolithic times and has been found in various cultures throughout the world. Manuscripts dating back to 1700 BC indicated that the Egyptians had some knowledge about symptoms of brain damage. Early views on the function of the brain regarded it to be a "cranial stuffing" of sorts. In Egypt, from the late Middle Kingdom onwards, the brain was regularly removed in preparation for mummification. It was believed at the time that the heart was the seat of intelligence. According to Herodotus, the first step of mummification was to take a crooked piece of iron, and with it draw out the brain through the nostrils, thus getting rid of a portion, while the skull is cleared of the rest by rinsing with drugs.

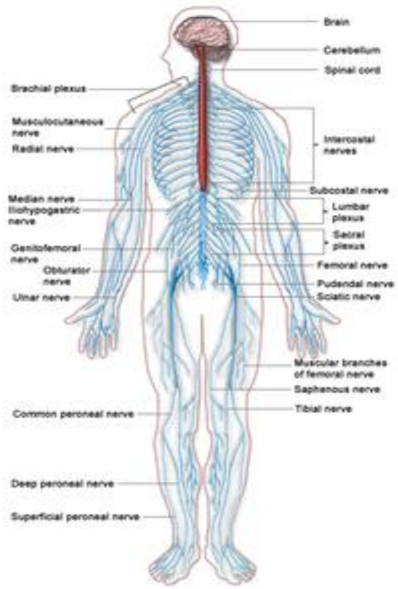
The view that the heart was the source of consciousness was not challenged until the time of the Greek physician Hippocrates. He believed that the brain was not only involved with sensation, since most specialized organs (e.g., eyes, ears, tongue) are located in the head near the brain, but was also the seat of intelligence. Plato also speculated that the brain was the seat of the rational part of the soul. Aristotle, however, believed the heart was the center of intelligence and that the brain regulated the amount of heat from the heart. This view was generally accepted until the Roman physician Galen, a follower of Hippocrates and physician to Roman gladiators, observed that his patients lost their mental faculties when they had sustained damage to their brains. Studies of the brain became more sophisticated after the invention of the microscope and the development of a staining procedure, by Camillo Golgi, during the late 1890s. The procedure used a silver chromate salt to reveal the intricate structures of individual neurons. His technique was used by Santiago Ramón y Cajal and led to the formation of the neuron doctrine, the hypothesis that the functional unit of the brain is the neuron. Golgi and Ramón y Cajal shared the Nobel Prize in Physiology or Medicine in 1906 for their extensive observations, descriptions, and categorizations of neurons throughout the brain. It was in the late 19th century that Emil du Bois-Reymond, Johannes Peter Müller, and Hermann von Helmholtz demonstrated that the electrical excitation of neurons predictably affected the electrical states of adjacent neurons.

In parallel with this research, work with brain-damaged patients by Paul Broca suggested that certain regions of the brain were responsible for certain functions. At the time, Broca's findings were seen as a confirmation of Franz Joseph Gall's theory that language was localized and that certain psychological functions were localized in specific areas of the cerebral cortex. The localization of function hypothesis was supported by observations of epileptic patients conducted by John Hughlings Jackson, who correctly inferred the organization of the motor cortex by watching the progression of seizures through the body. Carl Wernicke further developed the theory of the specialization of specific brain structures in language comprehension and production. Modern research still uses the Brodmann cerebral cytoarchitectonic map (referring to study of cell structure) anatomical definitions from this era in continuing to show that distinct areas of the cortex are activated in the execution of specific tasks.

In 1952, Alan Lloyd Hodgkin and Andrew Huxley presented a mathematical model for transmission of electrical signals in neurons of the giant axon of a squid, action potentials, and how they are initiated and propagated, known as the Hodgkin–Huxley model. In 1961 & 1962, Richard FitzHugh and J. Nagumo simplified Hodgkin–Huxley, in what is called the FitzHugh–Nagumo model. In 1962, Bernard Katz modeled neurotransmission across the space between neurons known as synapses. Beginning in 1966, Eric Kandel and collaborators examined biochemical changes in neurons associated with learning and memory storage. In 1981 Catherine Morris and Harold Lecar combined these models in the Morris–Lecar model. In 1984, J. L. Hindmarsh and R.M. Rose further modeled neurotransmission.

1.2. Modern Neuroscience

The scientific study of the nervous system has increased significantly during the second half of the twentieth century, principally due to advances in molecular biology, electrophysiology, and computational neuroscience. This has allowed neuroscientists to study the nervous system in all its aspects: how it is structured, how it works, how it develops, how it malfunctions, and how it can be changed. For example, it has become possible to understand, in much detail, the complex processes occurring within a single neuron. Neurons are cells specialized for communication. They are able to communicate with neurons and other cell types through specialized junctions called synapses, at which electrical or electrochemical signals can be transmitted from one cell to another. Many neurons extrude long thin filaments of protoplasm called axons, which may extend to distant parts of the body and are capable of rapidly carrying electrical signals, influencing the activity of other neurons, muscles, or glands at their termination points. A nervous system emerges from the assemblage of neurons that are connected to each other.



In vertebrates, the nervous system can be split into two parts, the central nervous system which includes the brain and spinal cord, and the peripheral nervous system. In many species, including all vertebrates, the nervous system is the most complex organ system in the body, with most of the complexity residing in the brain. The human brain alone contains around one hundred billion neurons and one hundred trillion synapses. It consists of thousands of distinguishable substructures, connected to each other in synaptic networks whose intricacies have only begun to be unraveled. The majority of the approximately 20,000–25,000 genes belonging to the human genome are expressed specifically in the brain. Due to the plasticity of the human brain, the structure of its synapses and their resulting functions change throughout life. Thus the challenge of making sense of all this complexity is formidable.

1.3. Molecular and Cellular Neuroscience

The study of the nervous system can be done at multiple levels, ranging from the molecular and cellular levels to the systems and cognitive levels. At the molecular level, the basic questions addressed in molecular neuroscience include the mechanisms by which neurons express and respond to molecular signals and how axons form complex connectivity patterns. At this level, tools from molecular biology and genetics are used to understand how neurons develop and how genetic changes affect biological functions. The morphology, molecular identity, and physiological characteristics of neurons and how they relate to different types of behavior are also of considerable interest.

The fundamental questions addressed in cellular neuroscience include the mechanisms of how neurons process signals physiologically and electrochemically. These questions include how signals are processed by neurites which are thin extensions from a neuronal cell body, consisting of dendrites (specialized to receive synaptic inputs from other neurons), axons (specialized to conduct nerve impulses called action potentials), and somas (the cell bodies of the neurons containing the nucleus), and how neurotransmitters and electrical signals are used to process information in a neuron. Another major area of neuroscience is directed at investigations of the development of the nervous system. These questions include the patterning and regionalization of the nervous system, neural stem cells, differentiation of neurons and glia, neuronal migration, axonal and dendritic development, trophic interactions, and synapse formation.

1.4. Neural Circuits and Systems

At the systems level, the questions addressed in systems neuroscience include how neural circuits are formed and used anatomically and physiologically to produce functions such as reflexes, multisensory integration, motor coordination, circadian rhythms, emotional responses, learning, and memory. In other words, they address how these neural circuits function and the mechanisms through which behaviors are generated. For example, systems level analysis addresses questions concerning specific sensory and motor modalities: How does vision work? How do songbirds learn new songs and bats localize with ultrasound? How does the somatosensory system process tactile information? The related fields of neuroethology and neuropsychology address the question of how neural substrates underlie specific animal and human behaviors. Neuroendocrinology and psychoneuroimmunology examine interactions between the nervous system and the endocrine and immune systems, respectively. Despite many advancements, the way networks of neurons produce complex cognitions and behaviors is still poorly understood.

1.5. Cognitive and Behavioral Neuroscience

At the cognitive level, cognitive neuroscience addresses the questions of how psychological functions are produced by neural circuitry. The emergence of powerful new measurement techniques such as neuroimaging, electrophysiology, and human genetic analysis combined with sophisticated experimental techniques from cognitive psychology allows neuroscientists and psychologists to address abstract questions such as how human cognition and emotion are mapped to specific neural substrates.

Neuroscience is also allied with the social and behavioral sciences as well as interdisciplinary fields such as neuroeconomics, decision theory, and social neuroscience to address complex questions about interactions of the brain with its environment. Ultimately neuroscientists would like to understand every aspect of the nervous system, including how it works, how it develops, how it malfunctions, and how it can be altered or repaired. The specific topics that form the main foci of research change over time, driven by an ever-expanding base of knowledge and the availability of increasingly sophisticated technical methods. Over the long term, improvements in technology have been the primary drivers of progress. Developments in electron microscopy, computers, electronics, functional brain imaging, and most recently genetics and genomics, have all been major drivers of progress.