# NEUROSCIENCE

## 8. BRANCHES OF NEUROSCIENCE – PART I

### 8.1. Cognitive Neuroscience

Cognitive neuroscience is an academic field concerned with the scientific study of biological substrates underlying cognition, with a specific focus on the neural substrates of mental processes. It addresses the questions of how psychological/cognitive functions are produced by neural circuits in the brain. Cognitive neuroscience is a branch of both psychology and neuroscience, overlapping with disciplines such as physiological psychology, cognitive psychology and neuropsychology. Cognitive neuroscience relies upon theories in cognitive science coupled with evidence from neuropsychology and computational modeling. Due to its multidisciplinary nature, cognitive neuroscientists may have various backgrounds. Other than the associated disciplines just mentioned, cognitive neuroscientists may have backgrounds in neurobiology, bioengineering, psychiatry, neurology, physics, computer science, linguistics, philosophy and mathematics. Methods employed in cognitive neuroscience include experimental paradigms from psychophysics and cognitive psychology, functional neuroimaging, electrophysiology, cognitive genomics and behavioral genetics. Studies of patients with cognitive deficits due to brain lesions constitute an important aspect of cognitive neuroscience. Theoretical approaches include computational neuroscience and cognitive psychology. Cognitive neuroscience can look at the effects of damage to the brain and subsequent changes in the thought processes due to changes in neural circuitry resulting from the ensued damage. Also, cognitive abilities based on brain development is studied and examined under the subfield of developmental cognitive neuroscience.

Cognitive neuroscience is an interdisciplinary area of study that has emerged from many other fields, perhaps most significantly neuroscience, psychology, and computer science. There were several stages in these disciplines that changed the way researchers approached their investigations and that led to the field becoming fully established. Although the task of cognitive neuroscience is to describe how the brain creates the mind, historically it has progressed by investigating how a certain area of the brain supports a given mental faculty. However, early efforts to subdivide the brain proved problematic. The phrenologist movement failed to supply a scientific basis for its theories and has since been rejected. The aggregate field view, meaning that all areas of the brain participated in all behavior, was also rejected as a result of brain mapping, which began with Hitzig and Fritsch's experiments and eventually developed through methods such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). Gestalt theory, neuropsychology, and the cognitive revolution were major turning points in the creation of cognitive neuroscience as a field, bringing together ideas and techniques that enabled researchers to make more links between behavior and its neural substrates.

## 8.2. Origins in Philosophy

Philosophers have always been interested in the mind. For example, Aristotle thought the brain was the body's cooling system and the capacity for intelligence was located in the heart. It has been suggested that the first person to believe otherwise was the Roman physician Galen in the 2$^{nd}$ century A.D., who declared that the brain was the source of mental activity although this has also been accredited to Alcmaeon. Psychology, a major contributing field to cognitive neuroscience, emerged from philosophical reasoning about the mind. During the 19$^{th}$ century, one of the predecessors to cognitive neuroscience was phrenology, a pseudoscientific approach that claimed that behavior could be determined by the shape of the scalp. In the early 19th century, Franz Joseph Gall and J. G. Spurzheim believed that the human brain was localized into approximately 35 different sections. In his book, *The Anatomy and Physiology of the Nervous System in General, and of the Brain in Particular*, Gall claimed that a larger bump in one of these areas meant that that area of the brain was used more frequently by that person. This theory gained significant public attention, leading to the publication of phrenology journals and the creation of phrenometers, which measured the bumps on a human subject's head. While phrenology remained a fixture at fairs and carnivals, it did not enjoy wide acceptance within the scientific community. The major criticism of phrenology is that researchers were not able to test theories empirically.

Perhaps the first serious attempts to localize mental functions to specific locations in the brain was by Broca and Wernicke. This was mostly achieved by studying the effects of injuries to different parts of the brain on psychological functions. In 1861, French neurologist Paul Broca came across a man who was able to understand language but unable to speak. The man could only produce the sound "tan". It was later discovered that the man had damage to an area of his left frontal lobe now known as Broca's area. Carl Wernicke, a German neurologist, found a patient who could speak fluently but non-sensibly. The patient had been the victim of a stroke, and could not understand spoken or written language. This patient had a lesion in the area where the left parietal and temporal lobes meet, now known as Wernicke's area. These cases, which suggested that lesions caused specific behavioral changes, strongly supported the localizationist view.

In 1870, German physicians Eduard Hitzig and Gustav Fritsch published their findings about the behavior of animals. Hitzig and Fritsch ran an electrical current through the cerebral cortex of a dog, causing different muscles to contract depending on which areas of the brain were electrically stimulated. This led to the proposition that individual functions are localized to specific areas of the brain rather than the cerebrum as a whole, as the aggregate field view suggests. Brodmann was also an important figure in brain mapping; his experiments based on Franz Nissl's tissue staining techniques divided the brain into fifty-two areas.

At the start of the 20th century, attitudes in America were characterized by pragmatism, which led to a preference for behaviorism as the primary approach in psychology. J.B. Watson was a key figure with his stimulus-response approach. By conducting experiments on animals he was aiming to be able to predict and control behavior. Behaviorism eventually failed because it could not provide realistic psychology of human action and thought. Thus it was too based in physical concepts to explain phenomena like memory and thought. This led to what is often termed as the cognitive revolution. Several findings in the 20th century continued to advance the field, such as the discovery of ocular dominance columns, recording of single nerve cells in animals, and coordination of eye and head movements. Experimental psychology was also significant in the foundation of cognitive neuroscience. Some particularly important results were the demonstration that some tasks are accomplished via discrete processing stages, the study of attention, and the notion that behavioral data do not provide enough information by themselves to explain mental processes. As a result, some experimental psychologists began to investigate neural bases of behavior. New brain mapping technology, particularly fMRI and PET, allowed researchers to investigate experimental strategies of cognitive psychology by observing brain function. Although this is often thought of as a new method (most of the technology is relatively recent), the underlying principle goes back as far as 1878 when blood flow was first associated with brain function.

## 8.3. Combining Neuroscience and Cognitive Science

Before the 1980s, interaction between neuroscience and cognitive science was scarce. The term 'cognitive neuroscience' was coined by George Miller and Michael Gazzaniga toward the end of the 1970s. Cognitive neuroscience began to integrate the newly laid theoretical ground in cognitive science, that emerged between the 1950s and 1960s, with approaches in experimental psychology, neuropsychology and neuroscience. Neuroscience was not established as a unified discipline until 1971. Recently the foci of research have expanded from the localization of brain area(s) for specific functions in the adult brain using a single technology, studies have been diverging in several different directions such as monitoring REM sleep via polygraphy, a machine that is capable of recording the electrical activity of a sleeping brain. Advances in non-invasive functional neuroimaging and associated data analysis methods have also made it possible to use highly naturalistic stimuli and tasks such as feature films depicting social interactions in cognitive neuroscience studies.

## 8.4. Behavioral Neuroscience (Biological Psychology)

Behavioral neuroscience, also known as biological psychology, biopsychology, or psychobiology is the application of the principles of biology (in particular neurobiology), to the study of physiological, genetic, and developmental mechanisms of behavior in humans and non-human animals. It typically investigates at the level of neurons, neurotransmitters, brain circuitry and the basic biological processes that underlie normal and abnormal behavior. Often, experiments in behavioral neuroscience involve non-human animal models (such as rats and mice, and non-human primates) which have implications for better understanding of human pathology and therefore contribute to evidence-based practice. Behavioral neuroscience as a scientific discipline emerged from a variety of scientific and philosophical traditions in the 18th and 19th centuries. In philosophy, people like René Descartes proposed physical models to explain animal and human behavior. Descartes, for example, suggested that the pineal gland, a midline unpaired structure in the brain of many organisms, was the point of contact between mind and body. Descartes also elaborated on a theory in which the pneumatics of bodily fluids could explain reflexes and other motor behavior.

Other philosophers also helped give birth to psychology. One of the earliest textbooks in the new field, *The Principles of Psychology* by William James (1890), argued that the scientific study of psychology should be grounded in an understanding of biology. James, like many early psychologists, had considerable training in physiology. The emergence of both psychology and behavioral neuroscience as legitimate sciences can be traced from the emergence of physiology from anatomy, particularly neuro-anatomy. Physiologists conducted experiments on living organisms, a practice that was distrusted by the dominant anatomists of the 18th and 19th centuries. The influential work of Claude Bernard, Charles Bell, and William Harvey helped to convince the scientific community that reliable data could be obtained from living subjects. Even before the 18th and 19th century, behavioral neuroscience was beginning to take form as far back as 1700 B.C. The questions that seemed to continually arise was what is the connection between the mind and body. The debate was formally referred to as the Mind-Body problem. There are two major schools of thought that attempt to resolve the Mind–Body problem; monism and dualism. Plato and Aristotle are two of several philosophers who participated in this debate. Plato believed that the brain was where all mental thought and processes happened. In contrast, Aristotle believed that the brain served the purpose of cooling down the emotions derived from the heart. The Mind-Body problem was a stepping stone toward attempting to understand the connection between the mind and body.

### 8.5. Topic Areas in Behavioral Neuroscience

In general, behavioral neuroscientists study similar themes and issues as academic psychologists, though limited by the need to use non-human animals. As a result, the bulk of literature in behavioral neuroscience deals with mental processes and behaviors that are shared across different animal models such as:

- **Sensation and perception**
- **Motivated behavior (hunger, thirst, sex)**
- **Control of movement**
- **Learning and memory**
- **Sleep and biological rhythms**
- **Emotion**

However, with increasing technical sophistication and with the development of more precise noninvasive methods that can be applied to human subjects, behavioral neuroscientists are beginning to contribute to other classical topic areas of psychology, philosophy, and linguistics, such as:

- **Language**
- **Reasoning and decision making**
- **Consciousness**

Behavioral neuroscience has also had a strong history of contributing to the understanding of medical disorders, including those that fall under the purview of clinical psychology and biological psychopathology (also known as abnormal psychology). Although animal models do not exist for all mental illnesses, the field has contributed important therapeutic data on a variety of conditions, including:

- **Parkinson's Disease -** Degenerative disorder of the central nervous system that often impairs the sufferer's motor skills and speech.
- **Huntington's Disease -** Rare inherited neurological disorder whose most obvious symptoms are abnormal body movements and a lack of coordination. It also affects a number of mental abilities and some aspects of personality.
- **Alzheimer's Disease -** Neurodegenerative disease that, in its most common form, is found in people over the age of 65 and is characterized by progressive cognitive deterioration, together with declining activities of daily living and by neuropsychiatric symptoms or behavioral changes.
- **Clinical Depression** - Common psychiatric disorder, characterized by a persistent lowering of mood, loss of interest in usual activities and diminished ability to experience pleasure.
- **Schizophrenia -** Psychiatric diagnosis that describes a mental illness characterized by impairments in the perception or expression of reality, most commonly manifesting as auditory hallucinations, paranoid or bizarre delusions or disorganized speech and thinking in the context of significant social or occupational dysfunction.
- **Autism -** Brain development disorder that impairs social interaction and communication, and causes restricted and repetitive behavior, all starting before a child is three years old.
- **Anxiety-** Physiological state characterized by cognitive, somatic, emotional, and behavioral components. These components combine to create the feelings that are typically recognized as fear, apprehension, or worry.
- **Drug abuse including alcoholism**

## 8.6. Affective Neuroscience

Affective neuroscience is the study of the neural mechanisms of emotion. This interdisciplinary field combines neuroscience with the psychological study of personality, emotion, and mood. Emotions are thought to be related to activity in brain areas that direct our attention, motivate our behavior, and determine the significance of what is going on around us. Pioneering work by Paul Broca (1878), James Papez (1937), and Paul D. MacLean (1952) suggested that emotion is related to a group of structures in the center of the brain called the limbic system, which includes the hypothalamus, cingulate cortex, hippocampi, and other structures. Research has shown that limbic structures are directly related to emotion, but non-limbic structures have been found to be of greater emotional relevance. In its broadest sense, cognition refers to all mental processes. However, the study of cognition has historically excluded emotion and focused on non-emotional processes (e.g., memory, attention, perception, action, problem solving and mental imagery). As a result, the study of the neural basis of non-emotional and emotional processes emerged as two separate fields: cognitive neuroscience and affective neuroscience. The distinction between non-emotional and emotional processes is now thought to be largely artificial, as the two types of processes often involve overlapping neural and mental mechanisms. Thus, when cognition is taken at its broadest definition, affective neuroscience could also be called the cognitive neuroscience of emotion.

## 8.7. Role of the Right Hemisphere in Emotion

The right hemisphere has been proposed over time as being directly involved in the processing of emotion. Scientific theory regarding the role of the right hemisphere has developed over time and resulted in several models of emotional functioning. C.K. Mills was one of the first researchers to propose a direct link between the right hemisphere and emotional processing, having observed decreased emotional processing in patients with lesions to the right hemisphere. Emotion was originally thought to be processed in the limbic system structures such as the hypothalamus and amygdala. As of the late 1980s to early 1990s however, neocortical structures were shown to have an involvement in emotion. These findings led to the development of the Right Hemisphere Hypothesis and the Valence Hypothesis. The right hemisphere hypothesis asserts that the right hemisphere of the neocortical structures is specialized for the expression and perception of emotion. The right hemisphere has been linked with mental strategies that are nonverbal, synthetic, integrative, holistic, and Gestalt which makes it ideal for processing emotion. The right hemisphere is more in touch with subcortical systems of autonomic arousal and attention as demonstrated in patients that have increased spatial neglect when damage is associated to the right brain as opposed to the left brain. Right hemisphere pathologies have also been linked with abnormal patterns of autonomic nervous system responses. These findings would help signify the relationship of the subcortical brain regions to the right hemisphere as having a strong connection.

The valence hypothesis acknowledges the right hemispheres role in emotion, but asserts that it is mainly focused on the processing of negative emotions whereas the left hemisphere processes positive emotions. The mode of processing of the two hemispheres has been the discussion of much debate. One version suggests the lack of a specific mode of processes, stating that the right hemisphere is solely negative emotion and the left brain is solely positive emotion. A second version suggests that there is a complex mode of processing that occurs, specifically that there is a hemispheric specialization for the expressing and experiencing of emotion, with the right hemisphere predominating in the experiencing of both positive and negative emotion. More recently, the frontal lobe has been the focus of a large amount of research, stating that the frontal lobes of both hemispheres are involved in the emotional state, while the right posterior hemisphere, the parietal and temporal lobes, is involved in the processing of emotion. Decreased right parietal lobe activity has been associated with depression and increased right parietal lobe activity with anxiety arousal. The increasing understanding of the role the different hemispheres play has led to increasingly complicated models, all based some way of the original valence model.

## 8.8. Cognitive Neuroscience Tasks in Affective Neuroscience Research

The emotion go/no-go task has been frequently used to study behavioral inhibition, particularly emotional modulation of this inhibition. A derivation of the original go/no-go paradigm, this task involves a combination of affective “go cues”, where the participant must make a motor response as quickly as possible, and affective “no-go cues,” where a response must be withheld. Because go cues are more common, the task is able to measure one’s ability to inhibit a response under different emotional conditions. The task is common in tests of emotion regulation, and is often paired with neuroimaging measures to localize relevant brain function in both healthy individuals and those with affective disorders. For example, go/no-go studies converge with other methodology to implicate areas of the prefrontal cortex during inhibition of emotionally valenced stimuli.

The emotional stroop task, an adaptation to the original stroop, measures attentional bias to emotional stimuli. Participants must name the ink color of presented words while ignoring the words themselves. In general, participants have more difficulty detaching attention from affectively valenced words, than neutral words.  This interference from valenced words is measured by the response latency in naming the color of neutral words as compared with emotional words. This task has been often used to test selective attention to threatening and other negatively valenced stimuli, most often in relation to psychopathology. Disorder specific attentional biases have been found for a variety of mental disorders. Similar findings have been attributed to threat words related to other anxiety disorders. However, other studies have questioned these findings. In fact, anxious participants in some studies show the stroop interference effect for both negative and positive words, when the words are matched for emotionality. This means that the specificity effects for various disorders may be largely attributable to the semantic relation of the words to the concerns of the disorder, rather than simply the emotionality of the words.