Outcomes in Neuroscience Education: Modular Theory and Network Theory

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A Prelude to Modular Theory

Few can contest the complicated and interdisciplinary origins of neuroscientific study, as its precise date of birth is obscure. However, it is important to place the first true and deliberate neuroscience studies in proper historical context so we can fully appreciate and understand why topics were studied through the lens of modular theory. Ancient Egyptians considered the brain and its organic projections to be little more than waste, instead believing that the true "seat of the soul" was the heart (Chudler, n.d.). This view was replicated in early Greek and biblical texts but represented the consolidation of personality and human character into physiological terms. Later, Hippocrates and his followers rebuked this dogma in early physiology, instead arguing that the brain was the major control center for the body and possessed three ventricles, each of which was responsible for a different mental faculty: imagination, reason, and memory (Chudler, n.d.). This view was supported by the Greek physician Galen who wrote extensively on the subject and had a profound influence on Enlightenment philosophers such as Rene Descartes (Chudler, n.d.).

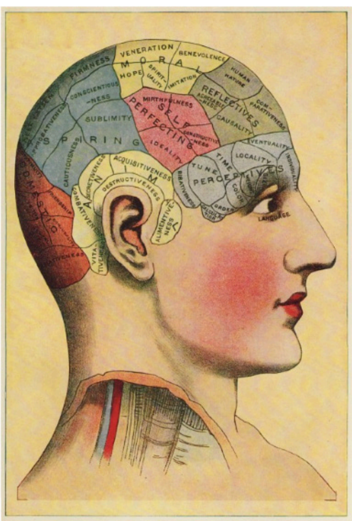

Figure 1: Phrenology chart [jpg]. (1920). Retrieved from https://www.sciencephoto.com/media/1002821/view/phrenology-chart

Hippocrates, Galen, and Descartes' collective writings emphasized an increasingly compartmentalized view of brain structure and function, a sentiment that came to a head in the early 19th century under the directorship of the German physiologist Franz Joseph Gall, the founder of the study of phrenology (Fodor, 1983). Phrenology borrowed major tenets of previous neurophysiological literature such as continuing to support the notion that the brain was the principal organ of the mind. Gall took those previous ideas to new maxims, claiming that the brain represented a collection of precisely localized cerebral organs with specific functions (Figure 1). The strength and proficiency of those particular functions, he argued, were proportional to the relative sizes and geometries of their respective skull regions.

Many would correctly conclude this understanding of neurophysiology to be akin to pseudoscience, but the dangerous influence phrenology has had on research in neuroscience must not be understated. The writings and lectures of Gall, his collaborators, and his students spread throughout the English-speaking world during the 19th century and fomented a number of debates about the methods employed to justify the major principles of phrenology (Yildirim & Sarikcioglu, 2004). Physiologist Jean Pierre Flourens performed experimental brain excisions on pigeons and observed their consequential behavior to demonstrate that the defined brain regions in phrenology had little experimental backing. These ablations, however, caused varied deficiencies and behavioral abnormalities suggesting that some interplay did still exist between brain regions and behavior (Yildirim & Sarikcioglu, 2004). An avalanche of research soon followed, characterizing and qualifying these interactions, along with the functions of a number of other brain and nerve components (Figure 2). Were it not for the early writings and claims of phrenology, the brain might have not been drawn into so many distinct components over the next two centuries.

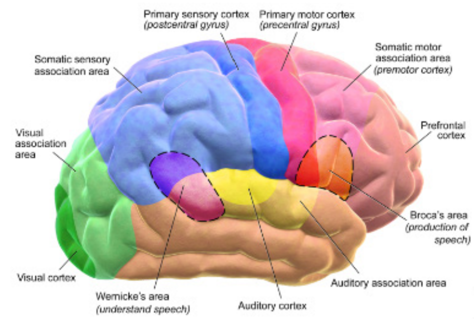

Figure 2: Blausen.com staff (2014). Medical gallery of Blausen Medical 2014 [png]. Retrieved from https://en.wikipedia.org/wiki/Human_brain#/media/File:Blausen_0102_Brain_Motor&Sensory_(flipped).png

Modular Theory Comes Under Scrutiny

Significant progress has been made over the last several decades in analyzing and characterizing brain regions and tissues. Our predecessor neurophysiologists of the late 1700s and 1800s lacked the sophisticated imaging technology we use today. Our imaging techniques provide a far more nuanced view of the brain, permitting us to see individual cells with profound resolution as seen in the Golgi staining technique (Finger, 2004). Golgi staining, developed by Camillo Golgi in 1873, entails the perfusing of silver nitrate into the cell bodies of neurons, the functional unit

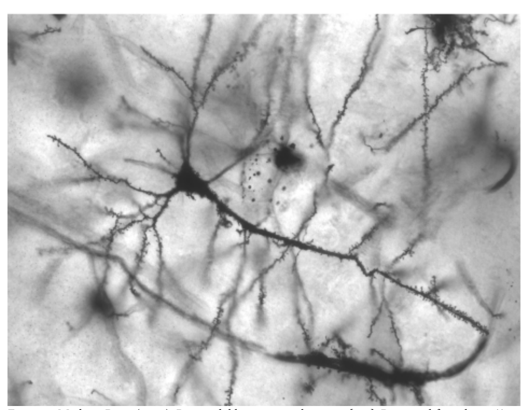

Figure 3: MethoxyRoxy (2005). Pyramidal hippocampal neuron [jpg]. Retrieved from https://commons.wikimedia.org/wiki/File:Pyramidal_hippocampal_neuron_40x.jpg

of the nervous system. The resulting stains depict darkened cell bodies and axons, the cellular projections that neurons use to communicate with one another (Figure 3). This advent in imaging technology allowed scientists to observe the actual connections and highways of communication between distant regions within the nervous system (Finger, 2004). Modular theory was beginning to be forced on the defense for the first time since its birth two centuries prior.

Cell imaging had its uses but had fairly limited applications when it came to in-vivo study of the brain and its operations. Cell and tissue isolation required the sacrifice of animal subjects and the collection of brain matter from cadavers. The first in-vivo studies of brain function and organization came about as the result of the invention of the x-ray in 1895 by Wilhelm Konrad Roentgen. The first images from this technology gave researchers a valuable opportunity to observe naturally-occurring brain deterioration in living human subjects and to relate the damage location and intensity with the behaviors and actions the subjects expressed (Finger, 2004). Early work demonstrated the lack of uniformity in brain tissue between humans. Regions thought to be related to language comprehension and speech production were found to differ in size and location between subjects. Furthermore, the degree of gyration of those and other brain regions was unique for everyone who was imaged (Triarhou, 2017). Overt dissimilarities in brain appearance began to give way to mounting criticism of the well-defined module mold of brain organization.

Both cell and brain imaging had important implications in research, but limited potential because each perspective provided only a snapshot of activity at a single given moment. It was not until the invention and implementation of imaging and even neurostimulator technologies that such a feat was possible. Positron emission tomography (PET) and magnetic resonance imaging (Figure 4) allowed scientists to observe the brain in action and directly measure the activity of brain regions through the circulation and exchange of blood and oxygen. These were complemented with experimental chemical stimulation, light stimulation through optogenetics, and Transcranial Magnetic Stimulation (Figure 5) to directly test relationships of stimulation and inhibition with brain activity (Badcock et al., 2019). These technologies revealed the limited importance of clusters of cells and tissues in action execution, and the greater relevance of their overarching and interconnected communication networks. However, a substantial disconnect still exists between what research has managed to reveal about the merits of network theory and what is being actively taught in classrooms.

Figure 4: Leblanc, R. (2009). Sagittal T1 Midline MRI Scan of Reigh's Brain [jpg]. Retrieved from https://www.flickr.com/photos/reighleblanc/3854685038.

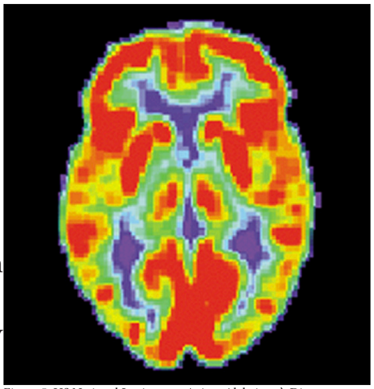

Figure 5: US National Institute on Aging, Alzheimer's Disease Education and Referral Center (2008). PET scan of a normal human brain [jpg]. Retrieved from https://commons.wikimedia.org/wiki/File:PET_Normal_brain.jpg.

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