Models of Functional Cerebral Localization at the Dawning of Modern Neurosurgery

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The concept of a functional cerebral localization gave the needed support for the development of neurosurgery as a specialty. It should be noted though that the presence of functions on discrete areas of the cortex was a very controversial topic at that time. The objective of this paper is to review models of cortical organization at the end of the 19th century, highlighting beliefs, theories, and controversies behind them. A better understanding of this historical moment is essential to appreciate the debate between holists and localizers that stirred neuroscientists worldwide in the first half of the 20th century.

INTRODUCTION

The paper of Victor A. H. Horsley (1857–1916) published in 1886 (29) was a landmark for neurosurgery. Improvements on aseptic technique and anesthesia permitted safer surgical procedures at the same time as cortical localization gave the needed support to reach lesions in the brain (37). At that time, two antagonist points of view (by Gall and Flourens) supported different theories about brain organization but conceptual flaws from both sides prolonged the debate for decades.

The objective of this paper is to review models of cortical organization at the end of the 19th century, highlighting theories and controversies behind them. A better understanding of this historical moment is essential to appreciate the debate between holists and localizers that stirred neuroscientists worldwide in the first half of the 20th century.

FRANZ J. GALL (1758–1828) AND PHRENOLOGY

Franz Gall, while still in his youth, noticed that several of his peers were able to easily recite texts from memory and linked this innate ability to a peculiar type of orbit. During his lifetime, he went on to develop a doctrine localizing psychic activities (such as perception, understanding, imagination, or trial) in the cerebral convolutions. He published his theory in a six-volume treatise (23) proposing that individuals with special skills or personality traits have hypertrophy in the areas of the brain related to these characteristics. The asymmetry of the cerebrum, in turn, was believed to create bulges in the skull. And inversely, analysis of the skull would therefore yield important information about the format of the brain and consequently on the abilities and behavior of the individual. The science of studying the head to appraise a person's personality traits, known as phrenology, gained widespread popular acceptance (11).

Referring back to his childhood peers, Gall concluded that speech must be located in anterior regions of the brain above the orbit, whose growth would lead to the characteristic shape of the eyes (Figure 1) (49). To support this claim, he described several patients with penetrating injuries to the anterior part of the skull that subsequently developed difficulties in naming. Despite drawing the wrong conclusions, several of his assumptions were based on elegant studies of anatomy (41). Nevertheless, Gall's greatest contribution was to draw attention to the fact that higher mental functions (hitherto regarded as attributes of the soul) were processed in specific areas of the brain. His materialist position produced friction with the Church that led to his exile from Austria.

JEAN P. FLOURENS (1794–1867) AND THE EQUIPOTENT CORTEX

Several authors fiercely contested phrenology. One of its earliest and most outspoken opponents was Jean Flourens, who wrote that "the entire doctrine of Gall is contained in two fundamental propositions, of which the first, that understanding resides exclusively in the brain, and the second, that each particular faculty of the understanding is provided in the brain with an organ proper to itself. Now, of these two propositions, there is certainly nothing new in the first one, and perhaps nothing true in the second" (p. 18) (22). Flourens employed progressive ablations and stimulation of the nervous system to define the function of each of its constituent parts, following the same method used by Luigi Rolando (1773–1831) in Italy some years earlier (44). The findings of Flourens were published in his classic book of 1824 (21). The author evaluated six components of the nervous system: peripheral nerves, spinal cord, medulla oblongata (brain stem), quadrigeminal protuberance, cerebellum, and cerebral hemispheres. He reported that stimulation of peripheral nerves, spinal cord, brain stem, and quadrigeminal protuberance triggered movement of muscles. On the other hand, cerebral hemispheres did not react to stimulation. Flourens thus concluded that

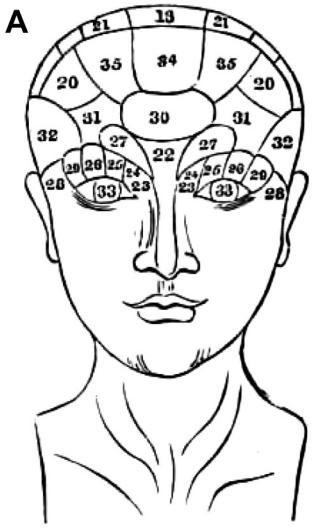

Figure 1. (**A**) Phrenologic chart depicting on the scalp areas related to different kinds of abilities. (**B**) Characteristic shape of the eyes related to verbal fluency (area 33). (Illustrations previously published by Vago AL: Orthodox Phrenology. London: Simpkin, Marshall; 1871 [49].)

this region was responsible for feelings, understanding, and will. Finally, the cerebellum was believed to coordinate body movements. According to this scheme, centers responsible for motor function and reason occupied different locations in the nervous system. Under this model, the mental faculties were indivisible and located diffusely throughout the cerebral hemispheres. In Flourens's opinion, intellectual capacity was directly related to the volume of the brain. Therefore, if part of the cerebrum was withdrawn, all its functions would remain intact albeit less efficient (cortical equipotentiality).

Although the two schools (Flourens's holistic theory and Gall's phrenology) shared the same period in history, Flourens's position was more respected in academia because of his scientific methodology.

SPEECH AS A MOTOR FUNCTION

Influenced by Gall, Jean Baptiste Bouilaud (1796–1881) compiled postmortem studies to locate the speech area in the brain. He collected several cases of patients with lesions to the frontal lobe and who presented speech disorders. Bouilaud, as did Gall, believed that the frontal lobes were what distinguished men from animals, being the center responsible for higher intellectual skills such as writing, arithmetic, and decision-making capacity. Nevertheless, his studies gained scant acceptance in scientific circles. In 1861, a debate within the Society of Anthropology of Paris would change this story. At this meeting, Louis Pierre Gratiolet (1815–1865) was defending the theory of brain equipotentiality when Ernest S. A. Auburtin (1825–1893) (son-in-law and follower of Bouilaud) called for clinical evidence of functional cortical localization. A few days after the debate, Paul P. Broca (1824–1880), also present at the meeting, saw a patient with a speech disorder at his clinic and called Auburtin to evaluate the case. Since the patient was deteriorating, it was the opportunity they had been looking for to produce a clinical–pathologic correlation (47). On examination, the patient was able to understand what he was told but unable to generate words (uttering just the sound "tam"). Moreover, the patient had no abnormality in his speech apparatus. Thus, Auburtin hypothesized involvement of the frontal lobe and at the autopsy Broca found a lesion affecting the posterior third frontal convolution of the left hemisphere (6). He called this language disorder associated with damage to the frontal lobe *aphemia*. Later, Armand Trousseau (1801–1867) would change this term to aphasia (48). According to Trousseau, Homer had used the term *aphasia* twice in his work with the meaning of loss of ability to speak without intelligence compromise, a denomination that corresponded better to the clinical status of such patients (p. 93) (3).

Unfortunately, the first scientific debate on cortical localization was centered on the complex function of language (10). However, it should be noted that at this early time, only the motor aspect of speech was taken into account. There was a concern, however, to emphasize the preservation of intelligence in these patients. According to John Frederic Bateman (1810–1889) "the intelligence is unaffected … the ideas are formed, but the means of communication with the external world do not exist" (p. 94) (3). This assumption facilitated acceptance in conservative circles, that had a vision rooted in the role of the spirit in the intellectual essence of the individual. Thus, injuries causing loss of speech must affect a region of the brain where either the memory of words or the memory of movements necessary to articulate words is located. Théodule A. Ribot (1839–1916) compared this model of brain organization with letters of the alphabet. Metaphorically, each cell would be able to save a letter. The union of letters would then generate any given word. Even though speech is more complex than the alphabet, the author pondered that there were six hundred million cells to store as many elements as were needed to reproduce any life experience (p. 28) (43).

Some dissenting voices have challenged these concepts. John Hughlings Jackson (1835–1911), considered way ahead of his time to be understood (27), defended that language was an expression of intelligence (both emotional and intellectual), involving wide areas of the cortex (30). In his opinion, Broca's area was just part of a bigger circuit (31). Despite controversies, the new concept took root and Broca's hypothesis became almost a dogma among scholars (16).

THE SPEECH AS A CIRCUIT

In 1868, the American physician Edward C. Seguin (1848–1898) made a compilation of the current literature and reported that approximately two thirds of 52 autopsies on patients with aphasia had lesions out of Broca's area (page 41). Thus, he concluded that lesion in the third convolution was not