Cerebral Localization in the Nineteenth Century — The Birth of a Science and its Modern Consequences

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Although many individuals contributed to the development of the science of cerebral localization, its conceptual framework is the work of a single man—John Hughlings Jackson (1835–1911), a Victorian physician practicing in London. Hughlings Jackson’s formulation of a neurological science consisted of an axiomatic basis, an experimental methodology, and a clinical neurophysiology. His axiom—that the brain is an exclusively sensorimotor machine—separated neurology from psychiatry and established a rigorous and sophisticated structure for the brain and mind. Hughlings Jackson’s experimental method utilized the focal lesion as a probe of brain function and created an evolutionary structure of somatotopic representation to explain clinical neurophysiology. His scientific theory of cerebral localization can be described as a weighted ordinal representation. Hughlings Jackson’s theory of weighted ordinal representation forms the scientific basis for modern neurology. Though this science is utilized daily by every neurologist and forms the basis of neuroscience, the consequences of Hughlings Jackson’s ideas are still not generally appreciated. For example, they imply the intrinsic inconsistency of some modern fields of neuroscience and neurology. Thus, “cognitive imaging” and the “neurology of art”—two topics of modern interest—are fundamentally oxymoronic according to the science of cerebral localization. Neuroscientists, therefore, still have much to learn from John Hughlings Jackson.

Keywords history of cerebral localization, history of neurology, cognitive imaging, neurology of art, historiography

Introduction

The history of cerebral localization in the nineteenth century is the history of the origin of a science. Like any science, many different perspectives on its emergence are possible, e.g., histories of its ideas, its institutions, or its technologies. In addition, each type of scientific history can be written from two opposing views, contextual and pedagogical. A pedagogical approach organizes the historical development of a science in a monotonic progression toward its modern structure and is therefore by definition anachronistic, while the contextual view emphasizes the human aspects of scientific discovery that are often irrational and haphazard. Contextual history is essential to understand the mechanics of scientific discovery, but a pedagogical organization is helpful if history is seen as an analytic tool used to validate or falsify modern scientific hypotheses. Because this is a historical and heuristic study of the ideas of cerebral localization, it has both contextual and pedagogical elements.
Although many individuals contributed to the development of a science of cerebral localization, its conceptual framework is the work of a single man—John Hughlings Jackson (1835–1911)—a Victorian physician practicing in London during the mid- to late nineteenth century. His scientific theory of clinical neurophysiology forms the basis of modern diagnostic neurology, provides the theoretical foundation for the neurosciences and separates neurology from psychiatry. The majority of this study examines the development of Hughlings Jackson’s theory of cerebral localization. To demonstrate the importance of a historical understanding of his work, the final section will show that some disciplines of contemporary neuroscience are logically meaningless since they are incompatible with the Jacksonian axiom that makes their parent science possible.

Methodology

Hughlings Jackson began his exclusive focus on diseases of the nervous system in the early 1860s, probably at the suggestion of Charles Edouard Brown-Séquard (1817–1894) (Hutchinson, 1911). At this time there was no specialty of neurology, and, as Hughlings Jackson immediately recognized, there was also no conceptual framework for the study of diseases of the nervous system (Hughlings Jackson, 1863a). By June of 1864 he had developed a methodology for investigating neurological disease and along the way he had discovered several important ideas that would form part of his science of cerebral localization (Hughlings Jackson, 1864).

When Hughlings Jackson began collecting cases of nervous system diseases the accepted method was to accumulate cases of the manifestations of a single disease, regardless of its location. Thus, cases of syphilis were collected without regard to the organ affected. Hughlings Jackson recognized that this type of information was not helpful in determining how the nervous system works. Next, he turned to evaluating the symptoms of multiple pathologies as they effect a single anatomic location, e.g., the pons or cerebellum (Hughlings Jackson, 1861). He again found that there was no consistent correlation between symptoms and postmortem pathology. Finally, Hughlings Jackson realized that an anatomic organ must consist of many discrete units, each of which had a single function. Hughlings Jackson probably learned of this principle in 1862 from a lecture he attended by Brown-Séquard where it was used in the premortem diagnosis of a pontine hemorrhage (Hughlings Jackson, 1862). Thereafter, Hughlings Jackson began collecting cases of what we would now term focal lesions that were restricted to these functional units. The use of focal lesions to determine nervous system physiology formed the methodology for the nascent science of cerebral localization.

With a tool available to investigate the nervous system, Hughlings Jackson initially turned his attention to disorders of speech and language (Hughlings Jackson, 1863b). This was a fortuitous choice because it brought immediately into focus the problem of brain functions and mental functions—a relationship whose lack of clarification had prevented a systematic analysis of neurophysiology for a millennia. Hughlings Jackson realized that a consistent and predictable science of the nervous system was possible only if it was seen as an exclusively sensorimotor machine.

The Sensorimotor Machine

Hughlings Jackson came to believe that the functions of the nervous system were restricted solely to sensation and movement. This idea is an essential prerequisite for
a science of cerebral localization and is the axiom of Hughlings Jackson’s clinical
neurophysiology.

In 1811 Charles Bell (1774–1842) demonstrated that stimulation of the anterior spinal
root produced movement, but the posterior root did not (Bell, 1811/1974). In 1822,
François Magendie (1783–1855) showed that division of the posterior root produced
sensory loss and anterior root division produced paralysis (Magendie, 1822). The resulting
concept that sensation and movement are separate at the spinal cord level became known
as the Bell–Magendie hypothesis.

In 1837, Marshall Hall (1790–1857) used his experimental work on amphibians to
conclude that there was a connection between sensation and movement at each spinal
level through the segmental reflex (Hall, 1837). He also suggested that impulses moved up
and down the spinal cord, citing experiments of Robert Boyle (1627–1691) and Robert
Whytt (1714–1766). The anatomical and functional separation of sensation and movement,
their connection in each spinal segment, and the continuity of ascending and descending
spinal pathways, became known as the law of reflex action.

Thomas Laycock (1812–1876) suggested that the law of reflex action applied to the
entire nervous system including the cortex in 1839 but did not exclude the possibility that
metaphysical functions, e.g., the soul, coexisted in the cortex (Laycock, 1845). Finally, in
1884, Hughlings Jackson expunged the metaphysical from neurophysiology by stating
that the entire nervous system was an exclusively sensorimotor machine (Hughlings
Jackson, 1884). By limiting the study of neurology to observable events of sensation and
movement, Hughlings Jackson provided the essential axiom for a science of cerebral
localization.

Evolution

The restriction of neurophysiology to sensorimotor events is necessary but not sufficient
to provide a functional description of the nervous system. For the latter, Hughlings
Jackson turned to the contemporary ideas of evolution. He was influenced by the applica-
tions of Darwinian evolution to diverse systems by Herbert Spencer (1820–1903)
(Hughlings Jackson, 1884). Hughlings Jackson adopted the language of evolution and
applied it to an organizational hierarchy. His evolutionary hierarchy consisted of four
characteristics: increasing complexity, increasing definiteness, increasing integration, and
increasing interconnections (Hughlings Jackson, 1884). He also believed, following Spen-
cer, that higher levels exert a controlling influence on lower ones (Hughlings Jackson,
1884). Thus destruction of a higher center results in two types of symptoms: a negative
symptom from the loss of the higher function and a positive symptom from the release of
a lower center from inhibitory control. For example, in the case of an incomplete stroke
affecting the leg, the negative symptom is partial paralysis and the positive symptom is
spastic gait.

But this evolutionary notion of higher and lower levels is still too general to provide a
useful diagnostic neurophysiology. We do not know exactly how Hughlings Jackson
derived his specific evolutionary structure of the nervous system since it is presented
essentially as a fait accompli. On the other hand, the following argument is a logical
sequence resulting in his conclusion. Since Hughlings Jackson considered the nervous
system to be a sensorimotor machine, its elements must contain a representation of the
physical body. That is, the nervous system must be a somatotopic map of the body. At its
simplest, the nervous system contains the spinal reflexes and, at its most complex, it
consists of highly integrated and cooperative sensorimotor behavior. If these form the
lowest and highest levels of the nervous system, the question is: how many levels are there in between? Given the positive and negative symptoms exemplified by paralysis and spasticity, as above, there must be at least one level between the spinal reflex and highly integrated fine control (i.e., the uncoordinated, spastic gait), and, in fact, there are no symptom complexes that require any more than one intervening level. Hence, Hughlings Jackson’s suggested a clinical neurophysiology consisting of three levels—lower, middle, and highest—that represent the impressions and movements of the body with increasing complexity, definiteness, integration, and interconnection.

Hughlings Jackson’s evolutionary analysis first appeared in 1874 (Hughlings Jackson, 1874–1876). Simultaneously, he was considering the specific nature of the body’s representational hierarchy and the way the different functional units within each level are related.

Weighting and Ordinality

In 1866 William H. Broadbent (1835–1907) proposed the following hypothesis as an explanation or the commonly observed absence of paralysis of muscles whose functions are bilaterally symmetric:

That where the muscles of the corresponding parts on opposite sides of the body act in concert, or act independently, either not at all, or with difficulty, the nerve-nuclei of these muscles are so connected by commissural fibers as to be *pro tanto* a single nucleus. This combined nucleus will have a set of fibers from each corpus striatum, and will usually be called into action by both, but it will be able to be excited by each singly, more or less completely according as the commissural connection between the two is more or less perfect. (Broadbent, 1866, p. 475)

He suggested that there must be bilateral innervation of such muscles so that if one side of the brain is damaged, the other can compensate for the loss. Interestingly, in his paper, he contrasted his clinical observations with those of Hughlings Jackson—demonstrating that by 1866 Hughlings Jackson’s reputation had reached a point where the established medical hierarchy noticed his ideas.

By 1874, Hughlings Jackson had incorporated Broadbent’s hypothesis in his theoretical clinical neurophysiology by recognizing that the representations of the body in the nervous system must have different weightings (Hughlings Jackson, 1874–1876). That is, the representations of some parts of the body are strongly unilaterally weighted so that, when damaged, paralysis occurs, whereas other parts are more equally represented and therefore unilateral brain damage has less affect. This emphasized to Hughlings Jackson that, even in the dominant hemisphere, each part of the body was not represented exclusively at one location—as in a homunculus—but rather each must be a heavily weighted element in a complete representation of the body. Additionally, he realized that if differential weighting was dynamic it could provide an explanation of recovery after brain damage—a well-known clinical phenomenon (Hughlings Jackson, 1884). When one area of the brain is damaged, other units can increase their weighting of the affected region thus compensating for the loss of function. Maximal plasticity is possible only if every functional unit of the nervous system at one level contains an entire copy of the next lower level. In other words the somatotopic representation must be ordinal. Thus, the lower, middle, and highest levels represent, re-represent, and re-re-re-present the body, respectively.
Medical Press and Circular 1874–1876

Though the individual elements of Jacksonian localization have been separated for this explication, in reality all of these ideas were simultaneously evolving during the period 1874–1876. This process can be followed in a series of 21 articles published in the Medical Press and Circular that were all entitled “On the Scientific and Empirical Investigations of Epilepsies” (Hughlings Jackson, 1874–1876). In this series, Hughlings Jackson can be seen progressing towards the final form of his theory of cerebral localization.

Jacksonian Cerebral Localization

In 1884 Hughlings Jackson delivered the Croonian lectures to the Royal College of Physicians in which his complete theoretical structure for clinical neurophysiology was presented (Hughlings Jackson, 1884). Weighted ordinal representation provides a consistent and reproducible foundation for a science of neurology and has successfully explained neuroscientific discoveries that could not have been imagined in Hughlings Jackson’s time. His restriction of neurology to sensorimotor physiology made both a science possible and also suggested a novel and sophisticated relationship between the brain and mind.

Concomitance

The experiments of a valid science must be reproducible. Consequently, in a clinical science of neurology, the experiments of nature (or neurological testing) require that the physiology of the brain be purely sensorimotor—the inclusion of any other processes results in identical lesions or stimuli producing inconsistent symptoms or responses. The complexity of interconnections in the highest centers may make predictability practically impossible, but, in principle, all nervous system functions must be sensorimotor. But clearly mental processes do arise from the brain and they can affect sensorimotor responses, and so the inevitable question arises of the relationship between functions of the brain and mind. In his Croonian lectures Hughlings Jackson addressed this problem (Hughlings Jackson, 1884). He believed the brain and mind were related by a doctrine of concomitance—they were like two clocks initially set to the same time, but running independently—in other words, completely correlated but causally unrelated. He believed the former because it seemed quite obvious that mental states accompany brain states, and he believed the latter because he thought that conservation of energy prevented nonphysical mental activity from provoking physical action. In modern terms, this combination of correlation and acausality defines a type of duality called complementarity. Duality should not be confused with dualism. It is not a philosophical assumption, but rather a meta-scientific principle that played a prominent role in the quantum revolution of the 1920s (Bohr, 1928) and does so currently in the most advanced modern physical theories (Maldacena, 1998). Complementarity results from unity at a higher level of abstraction. For example, heads and tails, night and day, and particle and wave are common examples of acausal correlation due to an underlying unity—specifically, the unity is found in the structure of a coin, rotation of the earth, and the wavefunction of Schrodinger’s equation, respectively. However, simply recognizing that mind and brain are complementary does not provide any information about the nature of their duality.

As a sensorimotor machine, all nervous system functions are reflex actions, and the logic of reflex action is deduction. This can be seen in many ways, but probably the
simplest and most rigorous is the following. A reflex is defined by the following syllogism, “If sensory stimulus ‘x’ occurs, then motor response ‘y’ will occur.” Thus, given stimulus, “x,” we are assured of response “y.” Of course, nothing limits the complexity of “x” or “y,” and hence this same description applies to spinal reflexes as well as the most complicated and highly integrated action of the highest centers. The above syllogism is an example of modus ponens, the rule of inference defining deduction—if “p” then “q”: “p” therefore “q.” Thus, a sensorimotor machine is a deductive machine.

Intelligence—a generic term for mental capacity—can be succinctly defined as the facility of induction, i.e., increasing intelligence is manifest by the increasing capacity to comprehend a general pattern shared by a set of specific observations. The greater the mental capacity, the more rapidly and accurately general laws can be induced from specific occurrences. Thus, the process of the mind is induction and the mind is an inductive machine.

This construction accurately reflects the complementarity of brain and mind since logic can be divided into the dual elements of induction and deduction—like night and day, heads and tails, and particle and wave. Since complementary pairs result from a unity at a higher level of abstraction, it is an interesting exercise to contemplate what logical unity manifests itself as induction and deduction, or mind and brain.

To summarize, the brain and mind are completely correlated but entirely distinct. They can be seen as two machines of antipodal character—the former deductive and the latter inductive—acting in concert. Each sensorimotor event is the substrate for a generalization, and each generalization is tested by additional sensorimotor events. Inductions accompany the reflexes of all levels but are most apparent in the highest centers where their occurrence is responsible for the mental processes that are humanity’s most distinguishing capacities. Brain and mind are complementary in the rigorous sense of the term and are reflections of a unity at a higher level of abstraction.

Hughlings Jackson and Modern Neuroscience

Hughlings Jackson’s insights are subtle and profound and, though they are essential for the existence of neuroscience, their consequences are not always recognized by contemporary practitioners. The importance of a historical understanding of his work can be seen in two areas of modern neuroscience that are explicitly oxymoronic according to Jacksonian principles. These are cognitive imaging and the neurology of art.

Cognitive imaging attempts to study mental functions by recording the patterns of cerebral activity that occur during cognitive tasks. For example, in the case of arithmetic, after control runs are subtracted to eliminate effects of sensory input, the remaining areas of brain activation are said to be where mental arithmetic resides. Of course, what is actually imaged is the cerebral machinery used in mental arithmetic. This distinction may at first seem purely pedantic, but it is critical. In contrast to functional imaging of sensorimotor tasks, where the recorded activity of the brain and the function being studied are identical, the cerebral activation recorded during a mental task has no relation to the underlying cognitive function. This disparity in the physical manifestations of the functions of brain and mind has a natural explanation yet is a source of persistent confusion. Sensorimotor functions are determined by the unique anatomy of human sense organs and muscles—i.e., they are determined by internal realities peculiar to humans—and are therefore identical patterns of human nervous system activity. Mental functions, on the other hand, create models of the external world—i.e., they are determined by external realities that are independent of humans. Mental functions have evolved to utilize the
machinery of the brain, but they cannot be defined by states of the nervous system. If they were so defined, then only a human brain could perform these functions, eliminating even the theoretical possibility of nonhuman intelligence. In exactly the same manner, studying the wires and beads of an abacus does not illuminate the nature of arithmetic, nor do the immense complexities of arithmetic—e.g., the various prime number conjectures—reside somewhere in the beads and wires of an abacus. As Hughlings Jackson recognized over a century ago, cognitive processes cannot be studied by examining the brain—an inductive process cannot be understood deductively any more than a wave can be understood by examining particles. What can be discovered are the particular structures of the human brain that are harnessed to perform cognitive functions, and certainly this is an interesting area of investigation—exactly equivalent to studying how an abacus, adding machine, or computer perform addition. However, this should not be confused with imaging or understanding cognitive functions themselves. The implicit assumption of cognitive imaging research—borrowed from sensorimotor imaging—that brain activity and a mental function are identical, is *prima facie* incorrect. The phrase “cognitive imaging” is logically vacuous since it is self-contradictory. It is incompatible with the essential axiom that makes a science of the nervous system possible.

This analysis does, however, raise an interesting question. Can functional imaging be used to experimentally test the proposition that brain states and mind states are identical? The answer is that it can if the correct question is asked of the technology. It is possible to design a relatively simple imaging experiment that would prove the non-localizability of mental functions and provide experimental confirmation of Hughlings Jackson’s insight into the complementarity of brain and mind.

The neurology of art is another explicitly oxymoronic concept. Other than the trivially mechanical parts of any artistic endeavor, art is creative and imaginative—an archetypal inductive process. A science of neurology depends on an exclusively sensorimotor neurophysiology—an archetypal deductive process. It is clear that the production of any form of art requires the integration of sensorimotor faculties, but these are unrelated to artistic creativity. Accumulation of information about the artistic or aesthetic effects associated with brain damage provides some indication of how the human mind uses the machinery of the brain to produce art. It can tell us nothing at all about the nature of art. As Hughlings Jackson discovered over a hundred years ago, artistic creativity is one of the best examples of what must be excluded to form a science of neurology—the intersection of art and neurology is empty—by definition, there can be no neurology of art.

**Conclusion**

After approximately four thousand years of clinical observations of nervous system pathology, and after at least two thousand years of speculation about clinical neurophysiology, John Hughlings Jackson created a science of cerebral localization in the mid-nineteenth century. The impediment to a consistent and reproducible scientific neurology was the conflation of nervous system and mental functions, which was removed by Hughlings Jackson’s fundamental axiom that the brain is an exclusively sensorimotor machine. Combining astute clinical observations and the prevailing intellectual milieu of his times, Hughlings Jackson proposed a theory of weighted ordinal representation that explained—and continues to explain—observations of the nervous system in health and disease. In fact, the full consequences of his insights have not yet been assimilated, as his principles directly imply that some modern disciplines of neuroscience are explicitly oxymoronic.
References


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