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Studi

The Cortical Localization of Language and the "Birth" of the Cognitive Neurosciences

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Abstract Whereas at the beginning of the XIXth century, Gall's description of "heads" received little scientific attention, by the end of the century, the cortical maps produced by the "cerebral cartography" of Ferrier were considered a true reproduction of the actual positions of the cortical functions. Gall conceived the brain as a mass of "organs", each constituting a specific instrument of an equally specific "faculty" of the soul. Ferrier, by contrast, considered the brain as a unitary organ made up of specific sensory and/or motor functional centres and of "associative" areas responsible for the more complex and integrated aspects of animal and human behaviour. Building on the clinical work of Broca and Jackson, the localizationistic model, supported by Ferrier's experimental evidences and clinical data, made it possible to replace the old neurological model with a new model for understanding the relation between the nervous system and behavior. Gall had wanted to put forward a new idea about the brain and mind, but he could only proffer a "speculative" theory devoid of clinical and experimental support in support of this idea. By the end of the century, however, the cognitive neurosciences had found their new paradigm: every mental function was considered to arise from motion and sensation, and from the integrative action of the nervous system.
KEYWORDS: Cognitive Neurosciences; Cerebral Localization; Models of Mind; History of Neuropsychology; Cognitive Diseases.

Riassunto *La localizzazione corticale del linguaggio e la "nascita" delle neuroscienze cognitive* – Se all'inizio del XIX secolo la descrizione dei crani di Gall riceve scarsa attenzione da parte della ricerca scientifica, a partire dalla fine del secolo le mappe corticali prodotte attraverso la "cartografia cerebrale" di Ferrier si considerano una riproduzione veritiera della posizione reale delle funzioni corticali. Gall concepisce il cervello alla stregua di una massa di "organi", ciascuno dei quali costituisce uno specifico strumento di una altrettanto specifica "facoltà" dell'anima. Al contrario Ferrier considera il cervello alla stregua di un organo unitario formato da specifici centri funzionali di carattere sensoriale e/o motorio e da specifiche aree "associative" responsabili degli aspetti più complessi ed integrati del comportamento animale e umano. Il modello localizzazionista costruito a partire dal lavoro clinico di Broca e Jackson e supportato dalle evidenze sperimentali e dai dati clinici di Ferrier rimpiazza il vecchio modello neurologico deputato alla spiegazione delle relazioni fra il sistema nervoso e il comportamento. Il fine di Gall è quello di proporre una nuova idea circa la mente e il cervello, tuttavia riesce solamente ad avanzare una teoria di carattere speculativo sprovvista di evidenza clinica e sperimentale a suo suffragio. Alla fine del secolo, tuttavia, le neuroscienze cognitive trovano il loro nuovo paradigma, secondo il quale ogni funzione mentale trae origine dal movimento, dalle sensazioni e dall'azione integrata del sistema nervoso.
PAROLE CHIAVE: Neuroscienze cognitive; Localizzazione cerebrale; Modelli della mente; Storia della neuropsicologia; Disturbi cognitivi.

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Cognitive neuroscience

IN THE LAST TWENTY YEARS, the cognitive neurosciences have developed impressively and contributed to deeper analysis of a wide range of topics. But what has been, in my opinion, even more critical for our understanding of mind and behaviour, is that they have made it possible to pose radically new questions and to explore new paths seeking for new answers.

> [Twenty years ago] we had a vibrant, young field on our hands. [Now] cognitive neuroscience is busting out all over. Fundamental stances are changing and new ideas are emerging. Everything from the view that individual neurons change their functional role through time to claims that our moral decision can be tracked in the brain are indicants of the range and the excitement of cognitive neuroscience [...] we will some day figure out how the brain works its magic and produces the human mind.[1]

The goal of cognitive neurosciences is in fact to understand the biological mechanisms that account for mental activity, the neural circuits that are established during development (even in the embryo)[2] and which permit individuals to process information in a complex and hierarchical manner: to perceive the world around them while actively interacting with it,[3] to recall perceptions from memory (in a sort of bodily activation of the same physical multisensorial and sensorimotor paths in which perception is grounded) and then to act on the basis of the memories of those perceptions within a complex system in anticipation/simulation of the consequences of actions.[4]

In their article on *Neural Science*, Albright, Jessell, Kandel and Posner call cognitive neuroscience "systematic neuroscience":

> historically, neural scientists have taken one of two approaches to these complex problems: reductionist or holistic. Reductionist, or bottom–up, approaches attempt to analyze the nervous system in terms of its elementary components, by examining one molecule, one cell, or one circuit at a time [...] Holistic, or top–down approaches, focus on mental functions in alert, behaving human beings and in intact experimentally accessible animals and attempt to relate these behaviors to the higher-order features of large systems of neurons [...] The holistic approach had its first success in the middle of the nineteenth century with the analysis of the behavioral consequences following selective lesions of the brain. Using this approach, clinical neurologists, led by the pioneering efforts of Paul Pierre Broca, discovered that different regions of the cerebral cortex of the human brain are not functionally equivalent [...] In the largest sense, these studies revealed that all mental processes, no matter how complex, derive from the brain and that the key to understanding any given mental process resides in understanding how coordinated signalling in interconnected brain regions gives rise to behaviour. Thus, one consequence of this top-down analysis has been initial demystification of aspects of mental function: of language, perception, action, learning and memory.[5]

Even if the historiographical reconstruction of the development of scientific knowledge is always and necessarily conventional in identifying a clear "starting point" for every theory or model of scientific practice, at least within the theoretical framework proposed by Kandel et al.[6] Broca played an outstanding role in "opening" neuroscientific research to the study of mind and its functions. So, let's examine the situation regarding these topics in the second half of the XIXth century.

Just a few words on phrenology

As is well known, the idea that different functions of the brain can be localized in specific areas of the cerebral organ commonly leads back to F.J Gall and to the theoretical

system, called *phrenology*, which he developed at the end of the eighteenth century and in the first decades of the 1800s.

Grounding his thought on naturalistic data taken from the observation of animal and human behaviour, from the collection and comparison of the skulls of animals from different species, and from the anatomical dissection of human brains, Gall claimed there was a strict link between behaviour, character, mind and brain in all living beings.

Thus, in the first half of the XIXth century, Phrenology offered a new, deeply articulated conception of man and animals, of their interaction with the natural environment, of the relationship between the nervous system and behaviour (specifically, between mind and brain). Phrenology was a theoretical system whose three main principles were:

► the mind is not a single entity, but an integrated system of various innate independent and specific faculties, attitudes and propensities, which operate autonomously and can be independently described;

► these various faculties and attitudes are localized in numerous cerebral "organs," which can be located on the surface of the brain;

► the shape of the head in some way "traces" that of the brain, since the skull is shaped in relation to the different volumes of the organs (which vary in size in proportion to the power of their respective faculties). Therefore, by examining the configuration of the skull (its cavities and prominences), it was considered possible to analyze the fundamental features of an individual's character, personality, and mental constitution. In the phrenological paradigm the brain was just a collection of different "mental organs", each being linked to a specific mental faculty (behavioural or cognitive faculty).[7]

Cerebral localization as a necessary epistemological device for clinicians

Although academic neurophysiologists refused to accept Gall's thinking, considering Phrenology to be nothing more than a dangerous philosophical (speculative) system, from the '20s clinicians became the driving

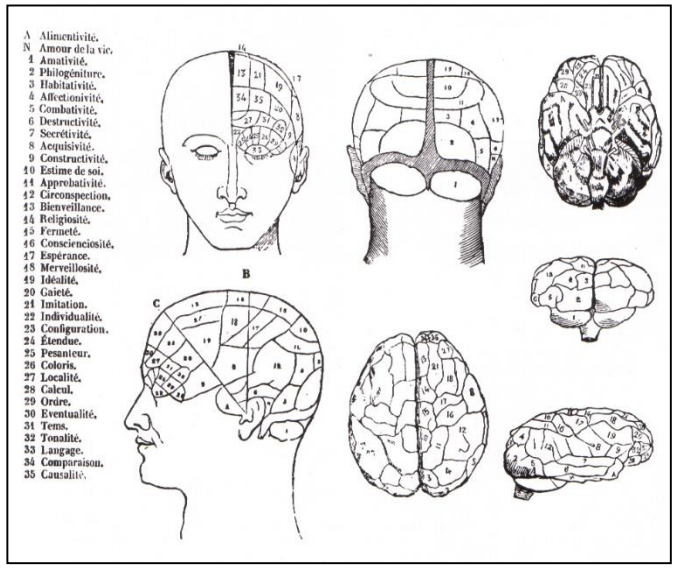

Figure 1. List of faculties with their anatomical seats, from: F.J. Gall, J.C. Spurzheim, *Anatomie et pysiologie du systèeme nerveux en général et du cerveu en particuler, avec des observations sur la possibilité de reconnaître plusieurs dispositions intellectuelles et morales de l'homme et des animaux par la configuration de leurs têtes*, 4 voll., 1810-1819

force in the development of a theory of hemispheric functioning which was compatible with pathological data, and that in some way rendered them comprehensible — a theory that, merely supposing the existence of specific cortical centers in charge of the performance of equally specific functions, could justify the high number and the selectivity of clinical phenomena related to disorders of the nervous system. In this regard, it is sufficient to remember the work of J.B. Bouillaud (1825) and M. Dax (1836).[8]

My thesis is that the epistemological needs of clinicians could not be satisfied in the absence of a theoretical model of mind deeply grounded in a rigorous knowledge of the anatomical and physiological aspects of the nervous system . As we will see, the sensory-motor theory of mind developed by Alexander Bain made it possible to look at the mind using the same paradigm used to examine the brain, that is, on the basis of scientific data, in the light of Muller's law on the specificity of nervous energy, Bell and Magendie's law on the sensory and motor pathways in the nervous system, and Helmholtz's research on the neuro- and psycho-physiology of perception.

In the second half of the XIXth century, in fact, the strong convergence ("triangulation" in epistemological terms) of three theoretical and scientific areas – neuroanatomy, neurophysiology and neuropsychology – gave rise to a new biology of mental functioning. Adopting the associationist approach to mind developed in its sensory-motor version by Alexander Bain, from 1855 onwards, European neuroscientists claimed the functional specialization of different cortical areas, supporting this claim with a combination of clinical studies and experimental research.

Sensory-motor associationism in Alexander Bain's thought

Situating his philosophical and psychological ideas within a theoretical framework based on empiricist and materialistic assumptions which had developed in France and in Great Britain from the XVIIIth century onwards (e.g. by Mettrie and Hartley), Bain made a fundamental contribution to the systematization and rigorous formalization of associationist thought, starting with the relationship between mind and body: in his view, the brain was the organ of the mind, and «we do not have any direct experience of the mind apart from the body and we cannot have any autonomous knowledge of it».[9]

In Bain's opinion, any drastic breaking with natural continuity was scientifically unacceptable; in order to highlight both the physical origin and the psychical characteristics of mental structure, of knowledge and – in general – of man's behavior, it is necessary to look at man as a biological system, as a functional unity in which mental and behavioral processes occur together in an adaptive way.

Overcoming the characteristic passivity attributed to the mind by the philosophical empiricist tradition, and explicitly referring to contemporary neurophysiology,[10] Bain stressed that in addition to sensation the motor component of the nervous system was of fundamental value; going even further, he identified the motor system as the primary explicative element for behavior and for knowledge:

> in treating of the senses, besides recognising the so-called muscular sense as distinct from the five senses, I have thought proper to assign to Movement and the feelings of movement a position preceding the Sensations of the senses; and have endeavoured to prove that the exercise of active energy originating in purely internal impulses, independent of the stimulus produced by outward impressions, is a primary fact of our constitution.[11]

The association of ideas developed through the formation of "cohesive links" – "acquired connections" between casual movements and sensations – was the basis of knowledge and of individual integrated experience. It was the fundamental mechanism of the whole cognitive

system, the essential constitutive element in the active and "constructive" nature of the mind.[12]

Associationism, in this version, was just a functional model; it was no longer a hypothesis about the *structure* of knowledge or the mind; instead, it was a theory, as scientific as it could be, about the *functioning* of the mind and the *behavior* of organisms in general, grounded in their body, their nervous system and the different ways[13] in which the interaction between living beings and their environment are possible.

Viewing the mind as a functional unity based on the sensory and motor functions of the nervous system and its integrative functions, Bain was able to explain mental function as Association, thereby replacing the various "faculties" that had been hypothesized, since the time of the Scholastic tradition, to explain the function of the mind with a single basic mechanism. By replacing the traditional "faculties" with an operative principle, a sort of "physical law of the mind", Bain stressed the importance, in understanding humans, of being able to clarify the relationship between mental capacities and cerebral functions.

The binomial "physiological-psychological" being, was in some way the epistemological equivalent of the "mind-body" and he claimed that it was necessary to adopt an integrated approach to increase our comprehension of the physiological mechanisms that take place in parallel with psychical processes.

In this way, Bain transformed Associationism: while Association Theory had initially been considered – in its XVII-XVIII century formulations – as an explanatory principle of a gnoseological kind, first as a mechanism of knowledge, and then as a way for constructing the whole mind starting from sensations, over time the concept became broader and was articulated in different directions through a progressive semantic shifting. In Bain's work, it became a logical and a neurological model at the same time: a paradigm, a complex conceptual framework in which the "intelligibility" of an organisms' mental and behavioral capacities could be located, a «natural science of mind» [in which] «the psychologist seeks to assign the natural conditions under which mental experience, as we are each (subjectively) aware of it, arises or comes to pass».[14]

In Bain's view, association – based on the capacity of the nervous system to integrate sensory and motor elements – was a fundamental operative principle of the animal world, as plastic and dynamic, as active and flexible as is the interaction of the organism with its environment, — an interaction that produces adaptive behaviors and knowledge and at the same time is produced by them.[15]

Philosophically and psychologically through his reflections on a fundamental physiological datum (Müller's «inborn energy of the nervous system» and the assumption that «if mind exists, it must exist somewhere and somehow in the brain»[16]), Bain transformed Associationism from a gnoseological conception into a theory of the genesis of behavior and mind. The newest neurophysiological discoveries (firstly, the studies of sense organs and sensory processes, contributed by authors like Müller, Purkinje and Helmholtz) were used to develop a new approach to the problem of perception and knowledge, and finally, to develop a theory largely based on the dynamic and active nature of perception and behavior in a sensory-motor view of mind and its cognitive functions.

Broca and the localization of motor language

In 1861 the first cortical function to be scientifically localized was language. Paul Pierre Broca was responsible for this first cerebral localization which he established by applying the anatomo-clinical method (a method typical of the Parisian Medical Schools at the beginning of the 1800s and which was later epistemologically reformulated in the work of Claude Bernard, 1865): i.e., by correlating clinical phenomena with observable pathological modifications in tissues and organs.

In this way, Broca demonstrated that lesions in the third left inferior frontal convolution produced a loss of the faculty of "motor

language" (this disturbance has since been called "motor aphasia", or "Broca's aphasia"), even though they do not imply a paralysis of muscles generally used in phonation; above all, he demonstrated that a language impairment could exist as a result of focal brain damage, without any concomitant cognitive disease linked to the selective damage.

I think it is of the utmost importance to consider the words of Broca (1861)[17] and to highlight their theoretical and methodological presuppositions, first of all with respect to phrenological thought and its development in the clinical work of Bouillaud:

> We know that the phrenological school placed at the front part of the brain, in one of the convolutions that lie on the orbital arch, the seat of the faculty of language. This opinion, which had been accepted, like so many others, without sufficient evidence, and which besides rested only on a very imperfect analysis of language phenomena, would have without doubt disappeared with the rest of the system, if Mr. Bouillaud had not saved it from foundering by making some important modifications to it, and by surrounding it with a parade of evidence borrowed above all from pathology. Without considering language as a simple faculty dependent on a single cerebral organ, and without looking into an area of a few millimeters for the location of this organ, as had been done by Gall's school, this professor was led by the analysis of a great number of clinical facts, followed by autopsies, to concede that certain lesions of the hemispheres abolish speech without destroying intelligence, and that the lesions always have their seat in the frontal lobes of the brain. He concluded that somewhere in these lobes, one or several convolutions holds under their dependence one of the elements essential to the complex phenomenon of speech, and thus, less restricted than in Gall's school, placed in the frontal lobes, without specifying further, the seat of the *faculty of articulated language*, which must not be confused with the *general faculty of language*.[18]

Assuming a basic differentiation between the sensory and motor pathways of the nervous system, and hypothesizing a sort of "reflection" of this functional differentiation in the complex internal articulation of the sensory and motor aspects of cognitive functions, Broca employed an anatomo-pathological method to deepen our understanding of language through an analysis of its different disorders.

> Pathology permits us to push the analysis further on to that which concerns articulated language, which is the most important and probably the most complex of all [...] There are cases where the general language faculty persists unaltered, where the auditory apparatus is intact, where all the muscles, not even excepting those of the voice and those of articulation, obey the will, and yet where a cerebral lesion abolishes articulated language. This abolition of speech, in individuals who are neither paralyzed nor idiots, constitutes a symptom so singular that it seems to me useful to designate it with a special name. I will give it, therefore, the name of *aphemia* (ἀ deprive; φήμί, I speak, I pronounce); it is only the faculty of articulating words that these patients lack. They hear and comprehend all that one says to them; they all have their intelligence; they emit vocal sounds with ease; they execute with their tongue and their lips movements much more extensive and energetic than those required for the articulation of sounds, and yet the perfectly sensible response that they would want to make is reduced to a very small number of articulated sounds, always the same and always performed in the same manner; their vocabulary, if can call it that, is composed of a short series of syllables, sometimes of a monosyllable that expresses everything, or rather that expresses nothing, for this unique word is most often a stranger to all vocabularies.[19]

Broca stresses that his patient has maintained the capacity to understand language and what he lacks is the ability to produce intentional verbal articulations. The focus of Broca's attention, here, is on the cognitive level of mental functions and, more in depth, on the motor realization of meaningful enunciations.

> Articulated language that they could once speak is always familiar to them, but they cannot execute the series of methodical and coordinated movements that correspond to the searched-for syllable. This which has died in them, it is not therefore the faculty of language, it is not the memory for words, nor is it the action of the nerves and muscles corresponding to phonation and to articulation, it is something else, it is a faculty particularly considered by Mr. Bouillaud as *the faculty that coordinates the proper movements of articulated language*, or more simply as the faculty of articulated language, since without it there is no articulation possible.[20]

According to Lorch's opinion, «Broca uses the classical language of psychical functions which was centuries old».[21] In Broca's words, language remains a "faculty" but we have to note the clear shift in his use of the term: what in the philosophical tradition was a sort of "power", with metaphysical origins, here becomes a new vision of mental functions, and the related possibility of considering their pathologies in terms of "syndromes".[22]

The fundamental divide between these two conceptions lies precisely in the way the neurologist looks at the mind: from within a functional analysis of well-defined and selective deficits. This in itself, clearly demonstrates the deep heuristic value of the clinico-pathological method for the development of neuropsychological studies.

> Whatever it might be, on the account of functional analysis, the existence of the special faculty of articulated language, such as that I have defined, cannot be placed in doubt, because a faculty that can perish alone, without those that are nearest to it being altered, is obviously a faculty independent of all the others, that is to say a special faculty.[23]

Although he used classical terminology, Broca was well aware of the theoretical implications of his work: what was at stake was the refutation or acceptance of a localizationistic model of mental functions – and this was a very "hot" topic in contemporary scientific debates. In the words of Lorch:

> The discussions and debates that Broca was involved in at the Paris Society of Anthropology were carried out in a particular politicized and religious context; contemporary beliefs about materialism and the status of the Soul influenced thinking in this neuroscientific domain.[24]

What the neurologist was seeking for was a way to "integrate"[25] scientific data with a range of theoretical issues.

> If all the cerebral faculties were as distinct, as clearly circumscribed as this one, one would finally have a positive point of departure to enter upon the question so controversial as cerebral localization. It is unfortunate that this is not so, and that the greatest obstacle to progress in this part of physiology comes from the insufficiency and uncertainty of the functional analysis that must necessarily precede research on the organs related to each function [...] What is in dispute today is not such-and-such phrenological system, but the very principle of localization, that is to say the prior question is knowing whether all parts of the brain that are concerned with thought have identical attributes or different attributes.[26]

Clearly, accepting the localization of verbal language implies a conceptualization of mind as a complex functional system based on a

functional cerebral architecture which is equally complex. Mind and brain have to be analysed together, to gain a real knowledge of both. This requires a theoretical framework in which many sources – clinical data, sensori-motor models of mind and psychological/epistemological assumptions about the mind-body problem – can converge using their findings to define a new understanding of human mind and behaviour, a theoretical framework that Broca considered still lacking "in the current state of science":

> The independence of this faculty [the faculty of articulated language – C.M.] is evinced by pathological observation [...] the pathological anatomy of *aphemia* can give something more than a solution to one particular question, and that it can throw a great deal of light on the general question of cerebral localization, by furnishing cerebral physiology with a point of departure, or rather a very precious point of comparison [...] There is in the mind groups of faculties, and in the brain, groups of convolutions; and the facts acquired up to now by science permit us to accept that the large regions of the mind correspond to the large regions of the brain. It is in this sense that the principle of localization seems to me, if not rigorously demonstrated, at least extremely probable. But to know with certainty whether each particular faculty has its own seat in a particular convolution, this is a question that seems to me all but insoluble in the current state of science.[27]

Thus, in the history of neuropsychology Broca's work is viewed as the "breakthrough" in our understanding of brain-behaviour and mind-brain relations.[28] "Motor aphasia", or "Broca's aphasia", was the first behavioral dysfunction to be precisely correlated with specific lesions and dysfunctions of the brain, and it represented a milestone for a new theory of cerebral localization.

Because of this, aphasia became the paradigm for understanding cognitive diseases and their correlation with lesions and/or dysfunctions of specific areas of the cerebral cortex, in the widest context of a theory that progressively delineated itself around the issue of the localization, on a clinical basis, of higher cortical functions.

In the words of Kandel, Broca's first localization of a mental function emancipated the study of mind and behaviour from metaphysics. The fundamental premise for a scientific and localizationistic approach to mind and its diseases, as we've seen – is the assumption of a sensori-motor associationist theoretical framework; a model of the brain which legitimizes the possibility of investigating cortical function not in terms of traditional faculties but rather in terms of simple and discreet sensory or motor elements connected to specific areas and functional zones of the hemispheres.

In any case, to be fully developed on the scientific level, Broca's localization, needed more clinical evidence and, above all, experimental confirmation.

If in the 1860s the clinical research of Broca had firmly established the localization of a linguistic function in the cerebral cortex, thus planting the seed for a scientifically grounded challenge[29] to the doctrine of the functional equipotentiality of the brain, this latter model, nevertheless, remained "dominant" in neurophysiology until the '70s, until the work of Fritsch and Hitzig and above all until Ferrier's experimental results. These experiments played a fundamental role in definitively establishing the sensory-motor nature of brain function, replacing for the old neurological model with a new model of the functioning of the nervous system and its relationship to behaviour.

Broca («in the current state of science...») had localized a "faculty" (the "faculty of articulated language"), but the cerebral localizations that, from the '70's onward, would be completed on an experimental basis, presupposed a drastic "reduction", in principles and methodologies, from the philosophical and psychological level to the sensory-motor level. This conceptual transformation of the associationist model was decisive because it was

critical to the development of a plurality of scientific research fields (from the study of behavior to that of the physiology and pathology of the nervous system, and moreover to the functioning of the mind and its diseases), insofar as it postulated the existence of a few underlying principles which could be determined using the scientific method.

Sensori-motor associationism reveals its strong heuristic value best in the work of Wernicke, and that of Jackson and Ferrier, among many others. It arose as a new "paradigm" for the modern cognitive neurosciences: every mental function "emerges" from motion and sensation, and from the integrative action of the nervous system.

John Hughlings Jackson

Initially an assistant to Brown-Séquard and from 1859 a neurologist and doctor at the National Hospital, already in 1864 Jackson (1835-1911) postulated the existence of cortical areas dedicated to motor function, basing his claims on his study of epileptic disorders. This implied cortical involvement in sensori-motor functions and a correlative sensori-motor connectionist interpretation of cognitive functions. Jackson was thus the first to postulate, merely on a hypothetico-deductive basis, the existence of specifically motor cortical areas. He formulated his theoretical system on the basis of clinical experience fundamentally centred on the study and the cure of epilepsy (the term "Jacksonian epilepsy" today is generally meant as a synonym for convulsive disorders localised and correlated to dysfunctions of specific motor areas of the cerebral cortex).

Starting in 1860, Jackson developed a theory of epilepsy and, more in general, of the organisation of the nervous system, based exclusively on clinical data and philosophical suggestions, a theory that was to be experimentally confirmed for the first time in 1870 with the work of Fritsch and Hitzig[30] and then by Ferrier.

> There is no more difficulty in supposing that there are certain convolutions superintending those delicate movements of the hands, which are under the immediate control of the mind than there is one, as Broca suggests, for movements of the tongue (articulatory organs) in purely mental operations.[31]

> In every paper written during and since 1866, whether on chorea, convulsions, or on the physiology of language, I have always written on the assumption that the cerebral hemisphere is made up of processes representing impressions and movement. It seems to me to be a necessary implication of the doctrine of Nervous Evolution as this is stated by Spencer.[32]

> The psychical, like the physical processes of the nervous system, can only be functions of complex combinations of motor and sensory nerves.[33]

Functional differentiation exists in the cerebral hemispheres; some areas of the cortex have motor functions, and in these areas "nervous discharges" take place that "descend" and diffuse themselves through the different levels in which the nervous system is structured, finally producing closely correlated convulsions, proportional to the place and the entity of the lesion. This outline of the epileptic disorder presupposes a highly complex and integrated model of the nervous system, but above all, it finally presupposes a unitary model, at the same time, for the nervous system, for behaviour and for man himself.

There is no separation, fracture, nor ontological distinction between the various levels of the nervous system and the behaviours they control, starting from the most elementary sensory-motor reflex and ending with the most complex intellectual phenomenon.[34] The surface of the cerebral hemispheres is also responsible for the control of sensations and movement, the minimal units starting from which, through progressive composition and "complexification", it is possible to determine all the aspects, healthy and pathological, of

cognition and behaviour.[35]

It is no longer possible to assume any dualism between cerebral hemispheres and the rest of the nervous system – such dualism is only a product of the philosophical dualism between brain and mind, body and soul. The cerebral cortex is simply the most integrated, most evolved and most recent development of the central nervous system, and the path followed by evolution – from the spinal cord to the surface of the hemispheres – has a correspondence with the inverse one of pathological "dissolution".[36]

Jackson did not believe in a precise functional "mosaic" nor did he support a diffuse representation of cortical functions; he developed, instead, a complex cerebral outline divided into functional motor areas with several gradations and overlaps: indeed, it was a localizationistic scheme, but in a substantially dynamic and flexible sense. He expresses his views on localization in this way:

> we shall, I think, not only discover the particular parts of the nervous system where certain groups of movements are most represented (anatomical localization), but, what is of equal importance, we shall also learn the order of action (physiological localization) in which those movements are therein represented.[37]

This model of nervous system function was required as an explicative scheme for epileptic disorders. Again clinical practice had demanded a formulation of hypotheses permitting localization of functional mechanisms in the brain – healthy and pathological – which could inform specific, directed interventions in the case of neurological disorders. In the background of Jacksonian theory, one strongly perceives the presence and the influence of some clear philosophical presuppositions: in the first place, reference is made to Spencer, who since '55 had begun to develop an evolutionist and global theory of the organism and of the link between behaviour and the nervous system.[38] Also evident are the suggestions that Jackson takes from the Sensorimotor Associationism of Bain and from the theory of the cerebral reflexes elaborated by Laycock.[39]

> The doctrine of evolution repudiates all schemes which make piebald divisions into ideational, etc., centres, and sensory and motor centres – all centres are sensory or motor, or both [...] The whole nervous system is a sensory-motor mechanism, a coordinating system from top to bottom. *A priori*, it seems reasonable to suppose that, if the highest centres have the same composition of the lower, being, like the lower, made up of cells and fibres, they have also the same constitution. It would be marvellous if, at a certain level, whether we call it one of evolution or not, there were a sudden change into centres of a different *kind* of constitution. Is it not enough difference that the highest centres of one nervous system are greatly more complicated than the lower?[40]

I would contend that this underscores the strong heuristic value of clinical medicine, its role in supporting a localizationistic paradigm is evident: it acts as a refined reactive, capable of isolating each element which contributes to the formation of complex functions. These were the basic issues of the "rising" field of neuropsychology and of the cognitive neurosciences.

Wernicke and "sensory aphasia" and Ferrier's experimental research

The discovery of motor aphasia was to be complemented, only a few years later, by the discovery of sensory aphasia, also called "Wernicke's aphasia", since Wernicke was the first to investigate its neuropsychological mechanism. In 1874 he identified a new "syndrome": "sensory aphasia", or "talking without understanding".[41] In this theoretical and methodological perspective, different clinical evidence could be understood by adopting just

one interpretative device. Aphasia became a model of brain function based on sensori-motor associationist assumptions.

During the same period, David Ferrier, using electrical stimulation and cortical ablation, and "triangulating" the resulting evidence with clinical data, put forward what he called "scientific phrenology" producing the first cortical maps of brain functions which offered the possibility of inferring, from neurological symptoms, clear indications on the exact localization of the cerebral sites responsible for the disorders.

Ferrier had studied logic and philosophy under Alexander Bain and at Bain's suggestion in 1864 he went to Heidelberg – where Helmholtz and Wundt were working – to study psychology, physiology and anatomy. In 1865, on his return to Scotland, he entered the Medical School of the University of Edinburgh, and three years later graduated in medicine. Equipped with this broad intellectual training, Ferrier carried on his clinical practice while pursuing his investigations into the physiology and pathology of the nervous system, and he became one of the pioneers in experimental research on this subject, bringing to his work the advantages of the practical knowledge of the physician.

His earliest important work was published in the reports of the West Riding Lunatic Asylum, where a pioneering school of neurology had been founded by Sir James Crichton-Browne in 1871. In fact, Crichton-Browne put the laboratory of the Asylum at Ferrier's disposal allowing him to experimentally test the excitability of the cortex demonstrated in 1870 by Fritsch and Hitzig. Thus, in March 1873 Ferrier embarked on a series of his experiments using systematic electrical stimulation – with faradic current – to investigate brains function in different animal species. In the 1873 Reports of the Asylum, Ferrier published his *Experimental Researches in Cerebral Physiology and Pathology*.

This was followed by the *Croonian Lectures* presented to the Royal College of Physicians of London in 1874 on *Localization of Function in the Brain*, and by further papers on the same subject published in the Philosophical Transactions of 1875. In 1876 Ferrier published his important work *The Functions of the Brain* which immediately resonated with the 'scientific community and was translated into many languages as was a second updated edition published in 1886.[42]. In the *Goulstonian Lectures* of 1878 *On the Localization of Cerebral Disease* Ferrier brought his experimental work into line with the pathological findings for cases of human cerebral diseases. In a succession of experiments, all accurately recorded, Ferrier proceeded to localize the motor and sensory centres through electrical stimulation and ablation; at the same time, he was able to experimentally test localizationistic hypotheses derived from the ideas of Jackson.

Ferrier supposed that electrical stimulation of the cortical centers artificially induced the manifestation of the functions characteristic of the single stimulated parts:

> by exciting in them a condition similar to that which in the normal order of events accompanies or coincides with psychical or

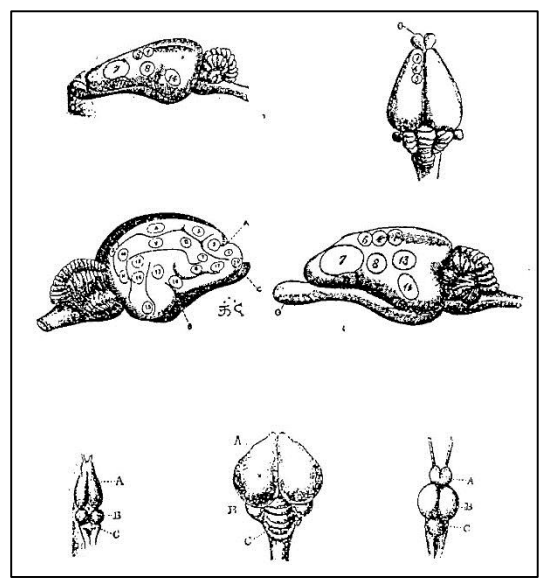

Figure 2. Brain of different animal species, from: D. Ferrier, *The Function of the Brain*, 1876

> volitional stimuli. Cerebral activity, likely the activity of every bodily organ, is associated with an active condition of the circulation. The electrical stimulus [...] excites in the cerebral hemispheres, locally or generally, that condition of hyperaemia which is the normal physiological condition of an organ functioning actively. So far, therefore, moderate stimulation seems to excite no abnormal action, and the muscular movements called forth by the irritation of the individual convolutions may be regarded as the artificial excitation of their normal functional activity.[43]

The only criterion for deducing the apparently intentional or goal directed nature of movements provoked by the stimulation of particular motor centers, is the same way in which we generally judge a behavior to be finalized: when there is a complex integration of movements to form a combined action aimed at the attainment of a goal.

It is obviously difficult to understand if the movements provoked by the electrical stimulation of particular zones of the cortex of the experimental subjects are actually intentional, but Ferrier nevertheless remarks, that generally speaking we can only recognize the intentional character even of human behaviour on the basis of our introspective valuation.

> Of course we have no other guide than our own consciousness to the interpretation of the actions of the lower animals, but as in ourselves or others we attribute such apparently purposive complex movements to ideation and volitional impulse, we may conclude that the cortical centres are not merely motor, and concerned with the outward manifestation of intelligence.[44]

Therefore, applying the same reasoning to different animal species, he goes on – using comparative approach – to characterizing the centers of voluntary movement and – even if in a more uncertain way – those of sensation, where no motor reaction follows the electrical stimulation, or perhaps some secondary motor reactions follow, generally associated with the various feelings.

> Whatever their exact function may be as regards sensation or the elaboration of sensations, it may be difficult to say, but that these parts (...) are not motor ganglia may be stated with the utmost certainty.[45]

On the basis of his experimental results, Ferrier emphasise the great practical usefulness of such research, also and above all in relation to the clinical applications of this physiological knowledge of the human nervous system.

From the beginning, Ferrier acknowledged and assumed Jackson's work as starting point and at the same time the ideal point of arrival for all his experimental work; the behavioural disorders connected to lesions and/or dysfunctions of the nervous system were considered as the human and natural equivalent of experimental results Ferrier had found for animals under artificial laboratory conditions.[46]

> In addition to the results of physiological experiments [...] some reference is made [...] to the facts furnished by the experiments of disease in man. These, however, require to be handled with the utmost caution, otherwise they may be made to support almost any doctrine however absurd [...] In the absence of any exact means of discrimination between the direct and indirect effects of pathological lesions, or of the relation between functional disturbance and structural alteration, little reliance can be placed on localization of function founded on the positive facts of cerebral disease alone. Clinical cases are mainly valuable in the confirmation of physiological experiments, and more especially as supplying negative instances. A case [...] of total destruction of a region in which a certain function is supposed to be localised, without loss or impairment of the function assigned to it, outweighs a thousand positive instances in which a causal relationship seems to be

established between the particular region and the function in question.[47]

Ferrier strongly underlines the great harmony and homology of the results obtained from different animal species («from the data of physiological experiment a foundation is obtained for constructing an anatomical homology of the convolutions»[48]) and in clinical practice; on the basis of this assumption he delineates his "model of the brain".

> The whole brain is regarded as divided into sensory and motor regions. The motor regions are regarded as essential for the execution of voluntary movements, and as the seat of a corresponding motor memory of motor ideas; the sensory regions being looked upon as the organic seat of ideas derived from sensory impressions.[49]

As regards the "hemispheres considered psychologically",

> in their subjective aspect the functions of the brain are synonymous with mental operations, the consideration of which belong to the science of psychology. The phenomena of consciousness cannot be investigated or explained by physiological methods only, but anatomical and physiological investigation of the substrata of consciousness may serve to elucidate some at least of the correlations between conditions of the brain and psychical manifestations.[50]

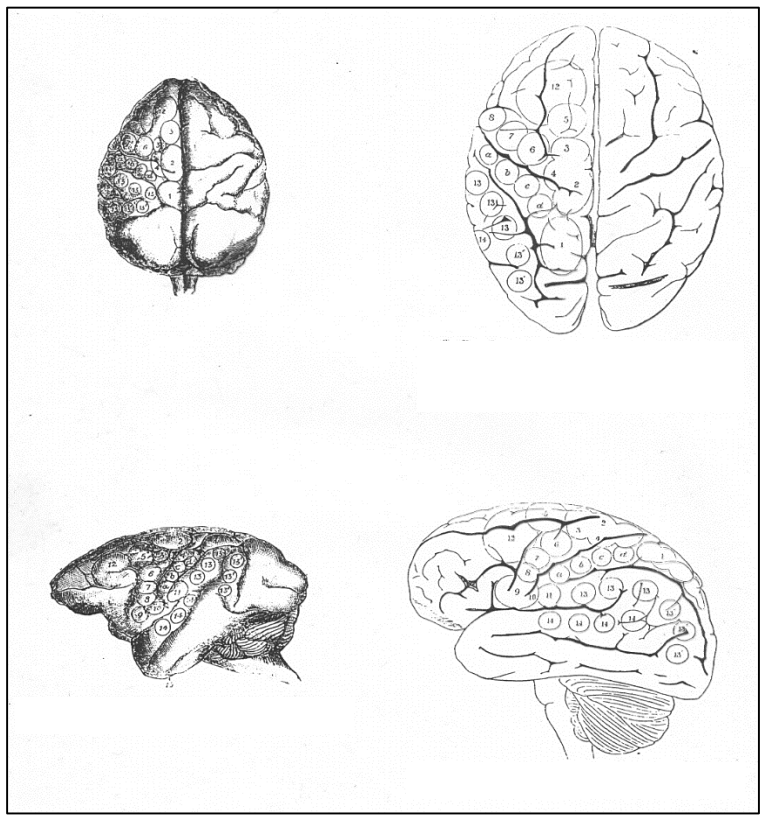

Figure 3. Brain maps of human and monkey, from: D. Ferrier, *The Function of the Brain*, 1976

He goes on to discuss, in the light of facts raised by physiological and pathological research, some of the relationships between physiological functions and the psychological functions of the brain.

> That the brain is the organ of the mind is a universally admitted axiom[51] [...] but we have no reason to believe that anything is superadded, or that the action of the cortical centres is of a different order from that of the most simple nervous apparatus; but rather that between the simplest reflex action and the most complex cerebral process there is a continuous unbroken gradation.[52]

Certainly, Ferrier continues, we don't know why consciousness rises only in relation to the activity of the cerebral hemispheres, and neither can we identify the two things or sustain that one is in a causal relationship with the other; that one is a subjective phenomenon while the other is objective. The only thing that can be claimed on scientific grounds on this point is – as stated by Laycock – that the two things are correlated, or – as claimed by Bain – that physical changes and mental modifications are the objective aspect and the subjective aspect of a "double-faced unity".[53]

As regards mental phenomena he says: «from the complexity of mental phenomena, and the participation in them of both motor and sensory substrata, any system of localization of mental faculties which does not take both factors into account must be radically false». Nevertheless, integrating experimental results and clinical evidence, he concludes by asserting that «a Scientific Phrenology is regarded as possible».[54]

At the end of the century, cerebral cartography was officially accepted as the science of the brain, and the incontestable value of cortical maps was recognized both on a theoretical and on a practical level. Ferrier's cerebral cartography ushered in a new era making it possible to correlate the symptoms of many neurological patients with their cerebral causes and also made neurosurgery possible (for example, in the case of intracranial tumors). Moreover, this research represented a significant step in the development of neuroscientific thought at the end of the century, firstly, for experimental neurophysiology, but also for the cognitive neurosciences and all those investigative fields that try to understand organisms in their interaction with the environment.

A new understanding of brain and mind and the "birth" of the cognitive neurosciences

If, at the beginning of the XIXth century, the "heads" designed by Gall's Phrenology did not receive much scientific attention, by the end of the century, the graphical representations produced by Ferrier were considered to be a true reproduction of the actual positions of the cortical functions.

In any case, the enormous distance which separated Ferrier's "maps" from the earliest cerebral cartography inspired by the organology of Franz Joseph Gall and by phrenology more generally, is evident: Gall, anatomist and "theorist" of the first half of the 1800s, viewed the brain as a mass of "organs", each being a specific instrument of an equally specific "faculty" of the soul.

Ferrier, experimental neurophysiologist at the end of the century, considered the brain simply as an extension of the central nervous system and described its functions in the light of the sensory-motor paradigm. The brain was a unitary organ made up of specific sensory and/or motor functional centres and "associative" areas responsible for the more complex and integrated aspects of animal and human behaviour.

Already in 1860, the clinical work of Broca had contributed to the localization of linguistic function in the cerebral cortex, however, the localizationistic model, still required confirmatory experimental evidence . Ferrier's experiments, from the '70's onward, played a fundamental role in establishing the sensory-motor nature of brain function.

It was now possible – at the end of the XIXth century - to replace the old neurological model with a new model of nervous system function

and its relationship to behavior.

Following Broca and Wernicke, and starting from the theoretical assumptions of Bain and Jackson, Ferrier worked on the level of experimental neurophysiology and decomposed even the more articulated behaviours and complex capacities of living beings into their minimal sensory and motor elements; elements to whose dynamic combination sensation and movement were referable and by means of which scientific understanding was rendered possible.

Gall wanted to offer a new model of the brain and its relations to the behaviour of organisms, but he was only able to offer a "speculative" theory devoid of clinical and experimental support to support his model. By contrast, at the end of the century, the neurosciences had found their new paradigm.

Broca had localized a "faculty" (the "faculty of articulated language"), but Ferrier's cerebral localizations presupposed a drastic "reduction", in principles and methodologies, from the philosophical and psychological level to the sensory-motor level.

There was, from the end the XIXth century onwards, a new paradigm for the neurosciences: every mental function arises from motion and sensation, and from the integrative action of the nervous system. From the convergence of clinical neurology, the anatomy and physiology of the nervous system, neuropsychology and associationist psychology, and in the light of the localizationistic paradigm, it was established that there is not a single central organ of language, but instead many cortical areas corresponding to different functional components which in concert govern language.

In this way, studies on aphasia shed a new light not only on language as a behavioural function, but on the organization of mind as a whole; and aphasia become the "paradigm" for mental functions in relation to the brain.

> Mystery and Ignorance are synonymous terms [...] all possible knowledge is open to the human mind, if a right method be adopted.[55]

Notes

[1] M.S. GAZZANIGA (ed.), *The Cognitive Neurosciences*, The MIT Press, Cambridge (MA) 2009, p. xv.

[2] See, for example, the works of E. Spelke on the development of cognitive functions.

[3] See the different action-perception models proposed in recent years by V. Gallese, C. Ginsburg, J. Decety, W. Prinz, F. Port and Tim van Gelder.

[4] The crucial importance of "anticipation" as a fundamental prerequisite of goal-directed actions is clearly stated already in the works of Bernstein. Today, it is fully analyzed by Berthoz. On simulation, see V. Gallese.

[5] T.D. ALBRIGHT, T.M. JESSELL, E.R. KANDEL, M.I. POSNER, *Neural Science: A Century of Progress and the Mysteries That Remain*, in: E.R. KANDEL (ed.), *Psychiatry, Psychoanalysis, and the New Biology of Mind*, APA Publishing, New York 2005, pp. 199-335, here p. 204.

[6] Historians of neurosciences commonly recognize that Broca's work inspired research in neuropsychology and aphasiology throughout Europe and North America, and his work prompted the development of a theory of mind based on the intersection of patterns of disorders and models of normal function which provided the epistemological basis for contemporary neuropsychology. See M. LORCH, *Re-examining Paul Broca's Initial Presentation of M. Leborgne: Understanding the Impetus for Brain and Language Research*, in: «Cortex», vol. XLVII, n. 10, 2011, pp. 128-135; N.F. DRONKERS, O. PLAISANT, M.T. IBA-ZIZEN, E.A. CABANIS, *Paul Broca's Historic Case: High Resolution MR Imaging of the Brains of Leborgne and Lelong*, in: «Brain», vol. CXXX, Pt. 5, 2007, pp. 1432-1441; S. FINGER, *The Birth of Localization Theory*, in: S. FINGER, F. BOLLER, K.L. TYLER (eds.), *History of Neurology*, Elsevier, Amsterdam 2010, pp. 117-128.

[7] See F.J. GALL, J.G. SPURZHEIM, *Anatomie et physiologie du système nerveux en général et du cerveau en particulier*, voll. I-II, F. Schoell, Paris 1810-1812; vol. III, Librairie grecque-latine-allemande, Paris 1818; vol. IV, N. Maze, Paris 1819.

[8] J.B. BOUILLAUD, *Recherches cliniques propres à démontrer que la perte de la parole correspond à la lésion des lobules antérieurs du cerveau, et a confirmer l'opinion de M. Gall, sur le siège de l'organe du langage articulé*, in: «Archives Générales de Médecine», III, t. 8 1825, pp. 25-45; M. DAX, *Lésions de la moitie gauche de l'encéphale coïncident*

avec l'oubli des signes de la pensée (1836), in: «Gazette hebdomadaire de médecine et de chirurgie», n. 2, 1865, pp. 254-260.

[9] A. BAIN, *The Senses and the Intellect*, Parker, London 1855, pp. v-vi.

[10] First of all, as we've said, the law of Bell and Magendie, and Müller's ideas on the fundamental role of the motor energy.

[11] A. BAIN, *The Senses and the Intellect*, cit.

[12] A. BAIN, *Mind and Body. The Theories of Their Relation*, Henry S. King & Co, London 1872, p. 79: «our course in life from first to last, although most at first, is trials and errors, groping and feeling our way, acting somehow, and judging of the result; and the general tendency of the law in question is to sustain us when we are in a good track, to turn off the steam when we are in a bad track».

[13] Think about the essential link between different degrees of complexity and plasticity of the nervous system ("freedom degrees" in articulating movement and goal oriented actions).

[14] A. BAIN, *Mind and Body. The Theories of Their Relation*, cit., p. 10.

[15] See *ivi*, p. 91: «for every act of memory, every exercise of bodily aptitude, every habit, recollection, train of ideas, there is a specific grouping, or co-ordination, of sensations and movements, by virtue of specific growths in the cell junctions».

[16] *Ivi*, p. 126.

[17] P.P. BROCA, *Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphemie*, in: «Bulletins de la Société d'Anthropologie», VI, 1861, pp. 330-357.

[18] P.P. BROCA, *Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphemie*, cit., pp. 330-331

[19] *Ivi*, p. 332.

[20] *Ivi*, p. 333.

[21] M. LORCH, *Re-examining Paul Broca's Initial Presentation of M. Leborgne: Understanding the Impetus for Brain and Language Research*, cit., p. 1232.

[22] See *ibidem*: «by giving it a name [*aphemie*] Broca was attempting to establish the notion of a clinical syndrome».

[23] P.P. BROCA, *Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphemie*, cit., p. 335.

[24] M. LORCH, *Re-examining Paul Broca's Initial Presentation of M. Leborgne: Understanding the Impetus for Brain and Language Research*, cit., p. 1233.

[25] Broca has been considered an integrationist for his attempt to synthesize competing views on the relations between mind and brain, mind and body, normal cognitive functions and selective mental deficits. See A. LA BERGE, *Dichotomy or Integration? Medical Microscopy and the Paris Clinical Tradition*, in: C. HANNAWAY, A. LA BERGE (eds.), *Constructing Paris Medicine*, Rodopi, Amsterdam 1998, pp. 1-69.

[26] P.P. BROCA, *Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphemie*, cit., pp. 336.

[27] *Ivi*, p. 338-339.

[28] R. CUBELLI, P. DE BASTIANI, *150 Years after Leborgne: Why is Paul Broca so Important in the History of Neuropsychology?*, in: «Cortex», vol. XLVII, n. 2, 2011, pp. 146-147; S. FINGER, *The Birth of Localization Theory*, cit.

[29] On the philosophical level, Gall – as we have seen – had already stated the functional differentiation of various cortical areas, but the frame of reference was very different.

[30] On the basis of his first works, produced in the '60s, Jackson himself claimed priority for his model with respect to the data obtained subsequently in the '70s from experiments first by Fritsch and Hitzig and then by Ferrier. In the *Preface* that he inserted in the '75 reprint of one of his works from '73 – a work meaningfully dedicated to Fritsch and Hitzig and Ferrier – he recalls explicitly and in detail numerous parts of his previous works (dating back to 1964), which clearly stress, on the one hand, the harmony and the strong correspondence of his postulates with Ferrier's first experimental results, on the other hand, the clear theoretical connections with the thought of Laycock, Spencer and Bain. *Clinical and Physiological Researches on the Nervous System. I. On the Localisation of Movements on the Brain*, J.&A. Churchill, London 1875: «I have for more than ten years, and before the experiments of Hitzig and Ferrier were made, held that convolutions contain nervous arrangements representing movements [...] It is a matter of extreme satisfaction to me to find that Dr. Ferrier [...] has come to a conclusion from the results of his experiments similar to that I have arrived at from clinical investigations [...] My opinion is that the experiments of Hitzig and Ferrier show, as they themselves believe, that parts of the cerebral hemispheres are centres for movements [...] Paralysis and convulsions are not only "symptoms of disease", but supply evidence bearing on the Localization of movement and impressions in the brain».

[31] J. HUGHLINGS JACKSON, *On the Study of Diseases of the Nervous System. A Lecture Delivered in June 1864*, in: «Clinical Lectures and Reports by the Medical and Surgical Staff of the London Hospital», vol. I, 1864, pp. 146–158.
[32] J. HUGHLINGS JACKSON, *Clinical and Physiological Researches on the Nervous System. I. On the Localisation of Movements on the Brain*, cit., p. xi.
[33] J. HUGHLINGS JACKSON, *Notes on the Physiology and Pathology of the Nervous System*, in: «Medical Times and Gazette», vol. II, 1868, pp. 177-179.
[34] See J. HUGHLINGS JACKSON, *On Some Implications of Dissolution of the Nervous System*, in: «Medical Press and Circular», vol. II, 1882, pp. 411-414 and 433-434, here p. 411: «the doctrine of evolution repudiates all schemes which make piebald divisions into ideational, etc., centres, and sensory and motor centres – all centres are sensory or motor, or both [...] The whole nervous system is a sensory-motor mechanism, a coordinating system from top to bottom».
[35] See J. HUGHLINGS JACKSON, *The Croonian Lecture on the Evolution and Dissolution of the Nervous System*, *Lecture III*, in: «British Medical Journal», I, n. 1215, 1884, pp. 703-707.
[36] Jackson draws the term "dissolution" from Spencer's *First Principles*, but a very similar concept had already been expressed by Laycock at the convention of 1844 of the British Medical Association. In Jackson's model of neurological disorders, the first nervous centres to be damaged are "the most elevated", those put at the head of the control of aware and voluntary behaviour, which exercise a sort of "hierarchical supervision" on the functioning of the inferior centres which are progressively less and less articulated and more automatic. What happens in the case of cortical lesions is the inactivation – temporary or permanent – of the highest level of behavioural control, and the "free" expression of the inferior centres as a consequence of the inhibition of advanced centres. The immediately successive level – healthy, but no longer subordinated to hierarchical control – takes over the leadership of behaviour and is therefore responsible for its pathological manifestations.
[37] J. HUGHLINGS JACKSON, *Observations on the Localization of Movements in the Cerebral Hemispheres*, in: «West Riding Lunatic Asylum Medical Reports», III, 1873, pp. 175-195, here p. 177.
[38] See J. HUGHLINGS JACKSON, *The Croonian Lecture on the Evolution and Dissolution of the Nervous System*, *Lecture II*, in: «British Medical Journal», I, n. 1214, 1884, pp. 660-663, here p. 662: «the doctrine of evolution implies the passage from the most organised to the least organised, or, in other terms, from the most general to the most specialised. Roughly, we say that there is a gradual "adding on" of the more and more special, a continual adding on of new organisations». There is a clear Spencerian flavour in these words.
[39] Laycock was Jackson's "teacher" at the York Medical School, and he introduced him to clinical neurology and to the School of Clinical-pathology in Paris.
[40] J. HUGHLINGS JACKSON, *The Croonian Lecture on the Evolution and Dissolution of the Nervous System*, *Lecture III*, cit., p. 703.
[41] See C. WERNICKE, *Der aphasische Symptomencomplex. Eine psychologische Studie auf anatomischer Basis*, Cohen & Weight, Breslau 1874.
[42] He was also one of the founders of *Brain* in 1878, the first editorial committee consisting, in addition to Ferrier, of Crichton-Browne, Bucknill and Jackson. *Brain* was the first English journal specifically devoted to the study of the nervous system and of brain-mind relations.
[43] D. FERRIER, *Experimental Researches in Cerebral Physiology and Pathology*, in: «West Riding Lunatic Asylum Medical Reports», III, 1873, pp. 30-96, here pp. 72-73.
[44] *Ibidem*.
[45] *Ivi*, p. 63.
[46] See D. FERRIER, *Pathological Illustration of Brain Function*, in: «The West Riding Lunatic Asylum Medical Reports», IV, 1874, pp. 30-62, here p. 49: «in the cortex of the brain, and related to each other in a constant and definite order, are individual centres for each separate muscular action involved in the epileptic convulsions, and the theory is that the convulsions are due to the discharge of these centres in a tolerably uniform manner, much depending on the primary source of the irritation».
[47] D. FERRIER, *The Functions of the Brain*, Smith Elder, London 1876, p. 270.
[48] *Ivi*, p. 231.
[49] D. FERRIER, *On the Localization of Functions of the Brain*, in: «The British Medical Journal», 1874, II, pp. 766-767, here p. 761.
[50] D. FERRIER, *The Functions of the Brain*, cit., p. 424.
[51] For Ferrier, the brain-mind link in terms of the organ-function relation is taken for granted, and yet only a few decades have passed since Gall, who for the first time established this link on a rigorously scientific basis.

[52] D. FERRIER, *The Functions of the Brain*, cit., p. 424.
[53] See A. BAIN, *Mind and Body. The Theories of Their Relation*, cit., p. 131.
[54] D. FERRIER, *On the Localization of Functions of the Brain*, cit., p. 761.
[55] T. LAYCOCK, *How Far Can the Relations of Body and Mind Be Investigated Scientifically and Practically? Introductory Address Delivered in the Second Section of Psychology at the Annual Meeting of the British Medical Association,* in: «British Medical Journal», 2, 1870, pp. 218-220, here p. 219.