

Broca's aphasia

Paul Broca's discovery of the area of the brain governing articulated language

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In 1861, in the bulletin of the Paris Anthropology Society, a short four-page note penned by Paul Broca (1824–1880) was published that would revolutionise neuroscience (**Text no. 1**). Paul Broca is not unknown. In Paris a hospital is named after him; there is also a street bearing his name in the 13th arrondissement, as well as in Bordeaux, Reims and Mantes-la-Jolie and no doubt elsewhere in France, and a square named after him in Sainte-Foy-la-Grande (Dordogne), where he was born.

THE BIRTH OF ANTHROPOLOGY

It is 1861, and the *Bulletin de la Société d'Anthropologie de Paris*, which published this short note, has reached its second volume. The scientific community is feverish with excitement. Charles Darwin has just published his iconoclastic work (*On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, 1859). Paul Broca subscribes to the transformist ideas that the Frenchman Jean-Baptiste de Monet, Chevalier de Lamarck (1744–1829), in his *Zoological Philosophy* (1809), had heralded half a century earlier. In 1859, Broca and his colleagues, all steeped in knowledge of natural history, found the Paris Anthropology Society.

Anthropology

The term *anthropology* appeared in 1655 in an anonymous English text. In 1735 the Swede Carl Linnaeus (1707–1778) introduced mankind into his zoological classification, including him alongside apes in the order of primates. In 1749 Georges Louis Leclerc, Count de Buffon, published his *Natural History of*

Man. It was the Germans Johann Friedrich Blumenbach (1752–1840) in 1795, then Emmanuel Kant (1724–1804) in 1798, who introduced the term “anthropology” as it is now understood. In 1827 Jean-Baptiste Bory de Saint-Vincent (1778–1846) published his *Zoological Essay on the Human Species*. In 1855 a Chair of Anthropology was established in Paris for Armand de Quatrefages (1810–1892). The Anthropology Society founded by Broca in 1859 followed on from the Society of the Observers of Man (*Société des Observateurs de l’Homme*), created in 1800, and the Paris Ethnology Society, founded in 1839 by the Frenchman William Edwards (1777–1842). These societies focused essentially on the ethnological (racial) and ethological (behavioural) aspects of human populations, neglecting the physical anthropology dear to Paul Broca. Broca also founded the Laboratory of Anthropology at the École des Hautes Études in 1868, the *Revue d’Anthropologie* in 1872, and the School of Anthropology in 1875.

The Paris Anthropology Society intended to put humankind in its proper place in the scale of living organisms and to study humans using the classic scientific methods of zoology and comparative anatomy (which the Frenchman Georges Cuvier (1769–1832) had developed), thereby rejecting the moral, religious and philosophical considerations that prevailed at the time. For the first time in the history of anatomy, the members of the society would undertake quantitative and statistical studies of humans, including one related to the size of the encephalon, or encephalisation.

Encephalisation, or the study of the size of the encephalon

The two texts on aphasia are an epiphenomenon in the works of Paul Broca. Another of his activities, directly related to the creation of the Anthropology Society, shows his concern to apply scientific methods to the study of mankind. One crucial issue consisted in linking intelligence, whether animal or human, to encephalic volume. Georges Cuvier (1769–1832), in his *Leçons d’anatomie comparée (Lessons in Comparative Anatomy, 1802)*, had studied this question and shown that the relationship between encephalic mass and body mass, which favoured small animals, was a poor method for measuring

intelligence. The discovery of fossilised human remains in 1838 by Jacques Boucher de Crèvecœur de Perthes (1788–1868), then in 1861 by Édouard Lartet (1801–1871), triggered a series of studies of mankind. We can cite as examples the American Samuel George Morton (1799–1851), who in 1839 measured intracranial volume and assimilated it to intellectual capacity, and his compatriot Othniel Charles Marsh (1832–1899), who in 1874 demonstrated the progression of intracranial volumes among mammals in the Tertiary Period. Following modernisation work to the city of Paris undertaken during the Second Empire under the supervision of Baron Georges Haussmann (1809–1891) – work which entailed the destruction of a number of cemeteries – skulls and other bones from the various historical eras of Old Paris were studied before being deposited in the Catacombs. Many anthropologists of the 1860s were interested in these questions. Aside from Paul Broca (« Sur le volume et la forme du cerveau suivant les individus et suivant les races », *BSAP* 1861, 2: 139–204 & 301–321 – « Sur la capacité des crânes parisiens des diverses époques », *BSAP* 1862, 3: 102–116, among others), other notable figures included Léonce Manouvrier (1850–1927), who wrote hundreds of pages on these measures (« Sur l'interprétation de la quantité dans l'encéphale et dans le cerveau en particulier », *BSAP* 1885, 2: 137–326 - Mémoires) and Louis Lapicque (1866–1952), who would devote over twenty articles to the subject between 1898 and 1941. It was the Russian Alexander von Brandt (1844–1932) who, in 1867, put forward the foundations of the modern approach to encephalisation by suggesting that encephalic volume should no longer be compared to the volume of a body, but to its surface (« Sur le rapport du poids du cerveau à celui du corps chez différents animaux », *Bulletin de la Société Impériale des Naturalistes de Moscou*, 40: 525–543, article in French).¹

1. For more information on encephalisation, see Roland Bauchot, « L'encéphalisation, aperçu historique », *Journal de psychologie normale et pathologique*, 1986, 81: 5–29.

THE LATERALISATION OF FUNCTIONS V. PERFECT SYMMETRY

Let's return to the note of 1861, which describes the circumstances that led Paul Broca, after the autopsy of the famous Tan-Tan, to hypothesise that the language centre was located in a convolution in the left frontal lobe.

M. Broca, in his statement, presents the brain of a man who died in his ward at the Bicêtre hospital, and who for the last twenty-one years of his life had lost his faculty of speech ... he could now pronounce only a single syllable, which ordinarily he repeated twice; whatever the question asked, he always replied tan, tan, accompanied by very varied expressive gestures.

... but one need only glance at the organ to see that the principal source and primitive seat of this softening is the middle section of the frontal lobe of the left hemisphere; that is where one finds the oldest and most extensive and advanced lesions ... Everything indicates, therefore, that in the present case, the lesion to the frontal lobe was the cause of the loss of speech.

It is remarkable that Broca arrived at such a conclusion given the extent to which understanding of the structure of the encephalon was still in limbo at this time. Indeed, it was not until 1875 that the Italian Camillo Golgi (1843–1926) developed a technique to stain cells using metal impregnation – which proved extremely useful for studying nerve cells and their projections – and it was only in 1899 that the Spaniard Santiago Ramon y Cajal (1852–1934), using Golgi's method, published the first images of the cellular structure of nervous tissue.

Metallic impregnation

This method, named *black reaction* by Golgi, and which uses silver nitrate, is based on the precipitation of silver when it comes into contact with cellular cytoplasm.

For reasons that are not fully understood, only a small number of neurons are impregnated by silver salt, which has two advantages. First, when a neuron is impregnated, its entire cytoplasm is affected: the silver stains not only the pericaryal area (which surrounds the nerve nucleus) but also the neuron's various dendritic or axonic projections. Second, as only a very small number of neurons are stained, it is possible to observe the path of the various dendrites and the axon against the colourless background of cerebral grey matter. The silver can be replaced by gold or osmium.

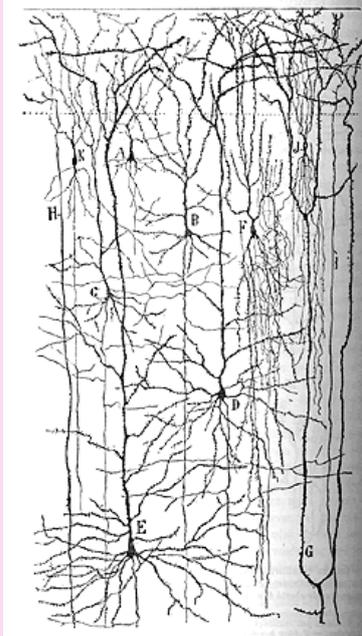


Figure 1: Cross-section of the human frontal cortex. Image obtained by Ramon y Cajal using Golgi's metallic impregnation method. The viewer can make out the form of neurons A–K. (Image Institut Ramon y Cajal)

In 1906, the Nobel committee, torn between the achievements of the inventor of histological staining and those of the scientist who had put it to use, jointly awarded the Nobel Prize for Medicine and Physiology to Golgi and Ramon y Cajal, in recognition of this advance in understanding of the brain.

In 1861, when Broca put forward his hypothesis, little more was known about the structure of the encephalon than the various afferent and efferent tracts² (white matter), those bundles of fibres that conduct nerve impulses. The rest of the encephalon (grey matter) was considered an amorphous mass of tissue acting, in each function it performed, as an undifferentiated whole (this opinion was upheld by Marie Jean Pierre Flourens, 1794–1867, the father of anaesthetics). It is true that, following Albert the Great (Albert von Bollstädt, c.1200–1280), scientists had sought to identify the various cerebral functions, but their work remained purely speculative. The phrenology of Franz Josef Gall (1758–1828) and Johann Gaspar Spurzheim (1776–1832) – which suggested haphazard localisations on the basis of bumps (*bosses*) on the skull (an idea the very same Flourens opposed) – was quickly abandoned, but not before spawning

2. Afferent neural pathways carry impulses towards the spinal cord or the encephalon (our reference here); efferent neural pathways carry impulses from the spinal cord or the encephalon to the organs.

Bertillonage.³ Phrenology left us with classic French expressions such as “Nicolas Bourbaki a la bosse des maths” (“Nicolas Bourbaki is a born mathematician”).⁴ In short, Broca was the first to localise one of the cerebral functions, language, on the basis of sound experimental evidence, and Broca was the true father of *cerebral localisations*.

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But his achievements did not stop there. Indeed, he localised the language centre in the *left* frontal lobe, for the autopsy indicated that Tan-Tan’s right frontal lobe was normal. Similarly, in 1874, the German Carl Wernicke (1848–1905) localised a nerve centre in the *left* temporal gyrus, close to the auditory cortex and connected by a nerve bundle to Broca’s area; a lesion to this nerve centre produces another form of aphasia, known as Wernicke’s aphasia. The afflicted patient is not unable to articulate words, but speaks in a kind of unintelligible jargon.

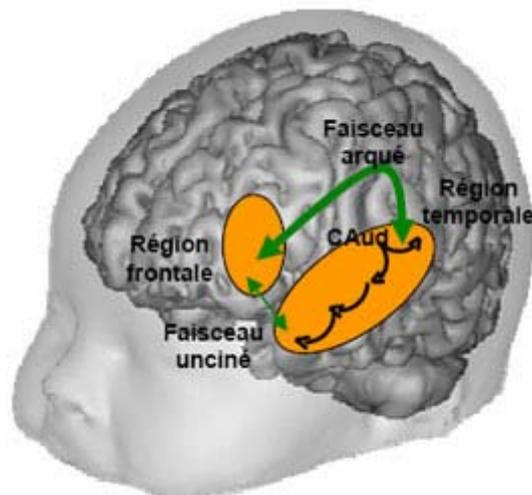


Figure 2: The superior temporal lobe, crucial to the comprehension of language, notably comprises the primary auditory cortex (CAud), which receives information from the ear, and Wernicke’s area in its posterior portion. In adults, the lower frontal region (Broca’s area) is involved in verbal production. (Image Direction des sciences de la vie – CEA)

In 1860, however, the encephalon was thought to be perfectly symmetrical. We know that each of the brain’s hemispheres receives sensory information from the opposite side of the body and that it then issues the latter its motor orders. The localisation of the language centre in a *single* hemisphere is therefore rather

3. Alphonse Bertillon (1853–1914) claimed to be able to identify criminals by measuring the contours, size and shape of their skull. He is also known for testifying for the prosecution as a handwriting expert during the Dreyfus Affair.

4. [Translator’s note] Literally, “Nicolas Bourbaki has a mathematician’s skull”.

surprising. What, then, is the role of the symmetrical region in the right frontal lobe, which does not have this language function – for it appeared quite normal during Tan-Tan’s autopsy – and did not compensate for the destruction of the contralateral area. Broca was perfectly aware of such an incongruity. Indeed, he would return to the unilateral localisation of the language centre on several occasions, publishing eleven notes on the subject between 1861 and 1866. We reproduce here the more structured of the articles, produced in 1863 (**Text no. 2**), in which he reports on other cases of aphasia observed by himself or by his colleagues and which are due to the destruction of a convolution in the left frontal lobe. The document gives an insight into the discussion that pitted doctors against anthropologists at this time. Some, including Louis Pierre Gratiolet (1815–1865) – who, like Broca, was born in Sainte-Foy-la-Grande – did not accept that the absence of speech could coexist with an otherwise intact intelligence, as is generally observed among aphasiacs, who understand what is said to them perfectly but do not have the means to reply in speech.

M. LINAS. M. Broca would therefore distinguish the ability to articulate words and the faculty of language.

M. BROCA. This distinction is obvious. One of the patients whom I mention had retained the ability to pronounce five words. Most aphemics have a limited vocabulary, which they use, however, to prove that they are still able to articulate words, though their faculty of language is extinguished.

M. GRATIOLET. These observations raise a great philosophical difficulty. How can the retention of intelligence coinciding with the loss of language be understood?

“Articulated language”, in this interesting debate, should be understood as intelligible language. The aphasic patient, though he may appear to have lost all possibility of making himself heard, has lost neither the vocabulary, grammar nor syntax necessary to correctly communicate with others. The only defect lies in the motor neurons in Broca’s area, which operate various muscles (pharynx, tongue, lips, vocal chords) involved in the articulation of spoken language.

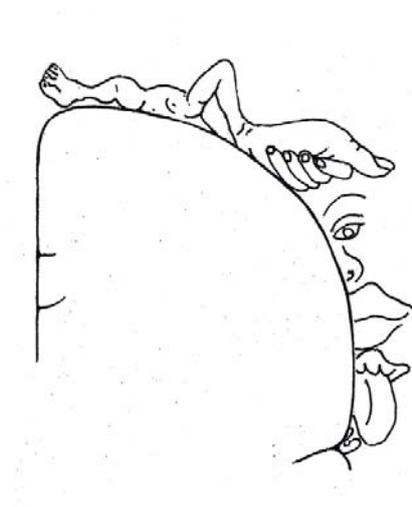


Figure 3: Stylised (Penfield) representation of the human cortical homunculus, in the ascending frontal convolution in the cerebral cortex. The electrical stimulation of a point on this surface will produce a movement in the corresponding body part. Note the relatively large size of the area corresponding to the buccopharyngeal muscles (which are involved in the articulation of language).

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The Dax affair

In 1863 Gustave Dax submitted two papers to the Academy of Medicine, one apparently written by his father in 1836 and which he had recently discovered in a drawer, and one penned by himself, which affirms that the “cerebral organ of speech has been found”. For Dax, this organ was located on the left side of the brain. Marc Dax’s (1770–1837) argument was based on the fact that the aphasics he had met were all more or less paralysed on their right side, which indicated that the language centre was located in the left hemisphere. According to his son, this paper had been delivered at a medical congress in Montpellier in 1836, though there is no trace of such a speech. Most curious of all is that Gustave, his son, does not once cite Broca in his paper, and bases his argument on only a very large sample of cases of aphasia-related motor paralysis, without having performed a single autopsy. Paul Broca never called into question the work of Marc Dax, of which he was most probably unaware. The fact remains, however, that he was the first to provide tangible evidence of this localisation.

Broca can therefore also be considered as the father of *cerebral lateralisations*. This paternity was enshrined by the name given to this cortical area in the left frontal lobe – *Broca’s area* – and that given to the loss of speech

due to the destruction of this area, whether as a result of syphilitic infection or, more commonly, a stroke – *Broca's aphasia*. This latter term (from the Greek privative *a* and *phasis*, "speech"), coined in 1864 by the neurologist Armand Trousseau (1801–1867), replaced the term *aphemia* (from the Greek privative *a* and *phemi*, "I speak") that Broca had used. Nowadays, the term *aphemia* designates another, generally temporary speech disorder entailed by some surgical operations. Broca's area, the nerve centre enabling the articulation of language, is part of the left ascending frontal convolution which governs the motor functions of the right side of the body; it is influenced by Wernicke's area, where intelligence and speech structure are coordinated. When the entire left ascending frontal convolution is affected by a stroke, this results in Broca's aphasia but also in the paralysis of the right side of the body, and in particular the right arm, which prevents the patient, if she is right-handed, from communicating with others in writing.

The principle of cerebral localisations is today sometimes taken to task in the name of *neuroplasticity*. It has indeed been noted – for example, in patients who have lost a finger after an accident – that brain neurons, which were nervously connected to that finger, respecialise to work with the remaining fingers – but this plasticity is limited, and as those who have become aphasic after a stroke know only too well, alas, neighbouring neurons rarely compensate for the loss of Broca's area.

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Another century would elapse before the discovery of the function of the cortical area of the right frontal lobe symmetrical to Broca's area. Two Canadians, the neurosurgeon Wilder Graves Penfield (1891–1976) and the neurologist Herbert Henri Jasper (1906–1999), provided the answer. Specialised in the surgical treatment of epilepsy, Penfield and Jasper took advantage of their trepanations to refine the localisation of brain functions. They exposed the cerebral cortex of the lightly anaesthetised patient to electrical stimulation, and the patient would indicate the localisation of various sensory or motor areas by identifying the corresponding somatic (bodily) areas.

In patients subject to the most severe epileptic fits, Penfield sectioned the corpus callosum, a commissure of nerve fibres that connects the two hemispheres of the brain. Such a practice prevents a motor seizure due to an

epileptogenic focus in one of the brain's hemispheres from spreading to the other hemisphere, and from there to the rest of the body. Patients who have undergone this operation are known as "split brains". The study of these patients is highly interesting and, following the pioneering work of Michael Gazzaniga (b.1939) and Roger Wolcott Sperry (1913–1994), it has been observed that each hemisphere, thus separated from its symmetrical counterpart, has its own personality, so to speak. Experiments carried out on split-brain patients – notably visual experiments in which each hemisphere receives only images from the opposite visual field – show that the left hemisphere is able to speak (Broca's and Wernicke's areas), but that it is unable to recognise landscapes or faces, even those of close friends or relations, whereas the right hemisphere, which does not speak, provides signals showing that it has correctly identified the faces of the patient's close family and friends among several photographs of unknown faces.

This discovery has led to the now common practice of facial composites (Identi-Kit® photos). The left frontal lobe is not able to describe an individual's face to the point of being able to recognise the person, unless this face has unusual features, but, when the facial composite is similar, the right frontal lobe is able to accurately identify the individual whose portrait it has seen (disregarding cases of twins or doubles).

Left-handed and right-handed

Brain asymmetry in the language centres has nothing to do with the lateralised motor performances that have long portrayed left-handed people as intellectually disadvantaged. Left-handers are estimated to represent 10–12% of the population in Western societies, and it is symptomatic that the adjective *gauche* is still synonymous with awkwardness. There is no substance to this, of course, and left-handed individuals might well point out that this motor characteristic, which has no effect on intellectual performance, has its advantages (isn't it the case that the best tennis players are often left-handed?). Brain asymmetry linked to functions such as language or reading are independent of this motor asymmetry and concern only 2% of individuals. Among the latter the right frontal lobe is the seat of speech, while the left identifies and recognises faces and landscapes.

CURRENT RESEARCH ON LATERALISATION

The lateralisation of brain functions mainly concerns intellectual functions. Recent research appears to show that it gradually develops in young children, notably during the reading process, which is also lateralised (Maryanne Wolf: *Proust and the Squid: The Story and Science of the Reading Brain*, 2007). Such lateralisations prevent the brain from becoming too large – intellectual functions do not have to be duplicated – but create a risk whereby any accident, especially of a vascular nature, may have harmful consequences. Following Penfield's work, an experimental method that makes it possible to work with normal individuals⁵ (rather than only with split brains) has revealed a more or less distinct lateral localisation of activities such as space geometry or melody analysis (which are generally attributed to the right hemisphere).

These results have often led to an excessive exaggeration of the consequences of these lateralisations. According to recent studies (which are sometimes controversial), aphasia following a stroke is more common on average among men than it is among women. The origin of this difference can be sought in embryonic development. We know that sexual differentiation in mammals is subject to the action of the male hormone. At the beginning, regardless of its definitive genetic sex, the embryo is "neutral". In the absence of the male sexual hormone, it develops female organs. It is the action of testosterone that causes organs to differentiate and become male. Yet this action also has an effect on the development of the encephalon. It is thought that cerebral lateralisation, under the influence of this hormonal action, is more marked among men than among women, which would explain why recovering speech is more difficult, or impossible, in men. Feminists immediately took issue with this claim – especially when cerebral masculinisation was adduced in some quarters as an explanation for the relative scarcity of women among the great mathematicians, orators and philosophers – arguing, quite rightly, that cultural differences – which are fortunately disappearing in Western societies – must also have played a role.

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5. An image presented to one visual field for a sufficiently short amount of time cannot be transferred across the corpus callosum. The initial results obtained from "split brains" can thus be tested in all "guinea pigs".

The lateralisation of the language centre has also been used, quite naturally, to identify a vestige of cranial asymmetry among humankind's fossilised ancestors. This asymmetry is thought to be the consequence of a difference in the volume or shape of the frontal lobes in the two hemispheres of the brain, and would provide evidence as to the emergence of articulated language. Such asymmetry can be detected among humanity's ancestors (see panel below) since the age of the *Australopithecus*, but the acquisition of articulated language is related not only to the size and shape of the larynx – which is difficult, if not impossible, to study in fossils – but also, no doubt, to brain volume. According to some contemporary anthropologists, speech could have emerged at the *Homo ergaster* stage, while, according to others, speech is specific to *Homo sapiens*. Studies of chimpanzees and bonobos show a capacity for non-verbalised communication that should urge caution in this area (Pascal Picq et al. *La plus belle Histoire du langage*, Seuil, 2008).

Human fossil remains

In 1891, the Dutchman Eugène Dubois (1858–1940) – who very much embraced the changes wrought by Charles Darwin's book as well as the work of anthropologists (Paul Broca and his colleagues) – sought to identify the famous "missing link" so dear to Darwin's detractors, who refused to accept apes as man's ancestors. He described the fossilised remains of a hominid, which he named *Pithecanthropus erectus* and which he had unearthed at Trinil (Java, then a Dutch colony). He did not choose this term at random: *Pithecanthropus* combines two ancient Greek words and signifies "ape-man", while the Latin *erectus* means "upright". Discover the missing link he most certainly had. The "Java Man" is now classed under the genus *Homo*, and the species *Homo erectus* alongside the Peking Man, discovered by Black Davidson in 1923 at Chou K'ou-tien (China) and named *Sinanthropus pekinensis*. The most famous of the fossilised hominids is Lucy (*Australopithecus afarensis*), discovered in 1974 at Hadar (Ethiopia) by Donald Johanson and Maurice Taieb and described by Yves Coppens. *Homo ergaster*, discovered in 1975 near to Lake Turkana in Kenya by Colin Groves and Vratislav Mazak, and then in 1984 by Richard Leakey and Alan Walker, is considered to be the ancestor of *Homo erectus*,

itself the predecessor to Neanderthal man (*Homo neanderthalensis*) and modern man (*Homo sapiens*).

Paul Broca's achievements were not limited to the fortuitous but fundamental discovery of the area of articulated language, nor to his anthropological work. He was a surgeon, anatomist, neurologist and biologist, but also a politician, writer and free thinker.

Indeed, scientific progress was long the work of enlightened amateurs or very eclectic scientists. The professional researcher is a recent creation, and immediately brings in tow the question of profitability. Can a society afford to finance research without any guarantee of success? The opposition between fundamental and applied research (*research and development*) is a sign of this dilemma. The snag is that great discoveries have more often been the result of accident than of targeted research. Paul Broca opened a new chapter in our knowledge of the nervous system because he performed a – I suppose, routine – autopsy of one of his aphasic patients. By imposing precise timescales on fundamental research – as is often the case nowadays – we run the risk of missing a potentially important discovery.



(September 2009)

(Translated in English by Helen Tomlinson, October 2014)