

# Twilight of an era: from the ventricular doctrine to the corticocentric model

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## ABSTRACT

**Introduction.** Over the course of history, different solutions have been proposed to elucidate the anatomical location of psychic activity and the mechanisms through which it occurs. For centuries, the ventricular doctrine and the theory of animal spirits were the standard model for explaining the anatomy and physiology of the brain. With the advent of the 17th century, these classical dogmas were rejected and progressively replaced by concepts and theories that were better aligned with the anatomical and physiological facts.

**Development.** In the 17th century, several authors asserted that the cerebral cortex was the seat of psychic activity, openly questioning the ventricular doctrine. This scientific revolution was supported by Caspar Bauhin, Johann Wepfer, Thomas Willis, and Marcello Malpighi. A hundred years later, authors including Emanuel Swedenborg and Georg Procházka not only located mental life in the cerebral cortex, but also suggested that this structure was made up of specialised functional regions. These ideas were the precursor to the cortical localisationism of the 19th century.

**Conclusions.** The 17th and 18th centuries were a period of transition from classical/medieval medical thought, represented by the ventricular theory, to modern medical thought, which situates psychic life in the cerebral cortex.

## KEYWORDS

Cerebral ventricles, cerebral cortex, animal spirits, cortical localisation, neuroanatomy, neurophysiology.

## Introduction

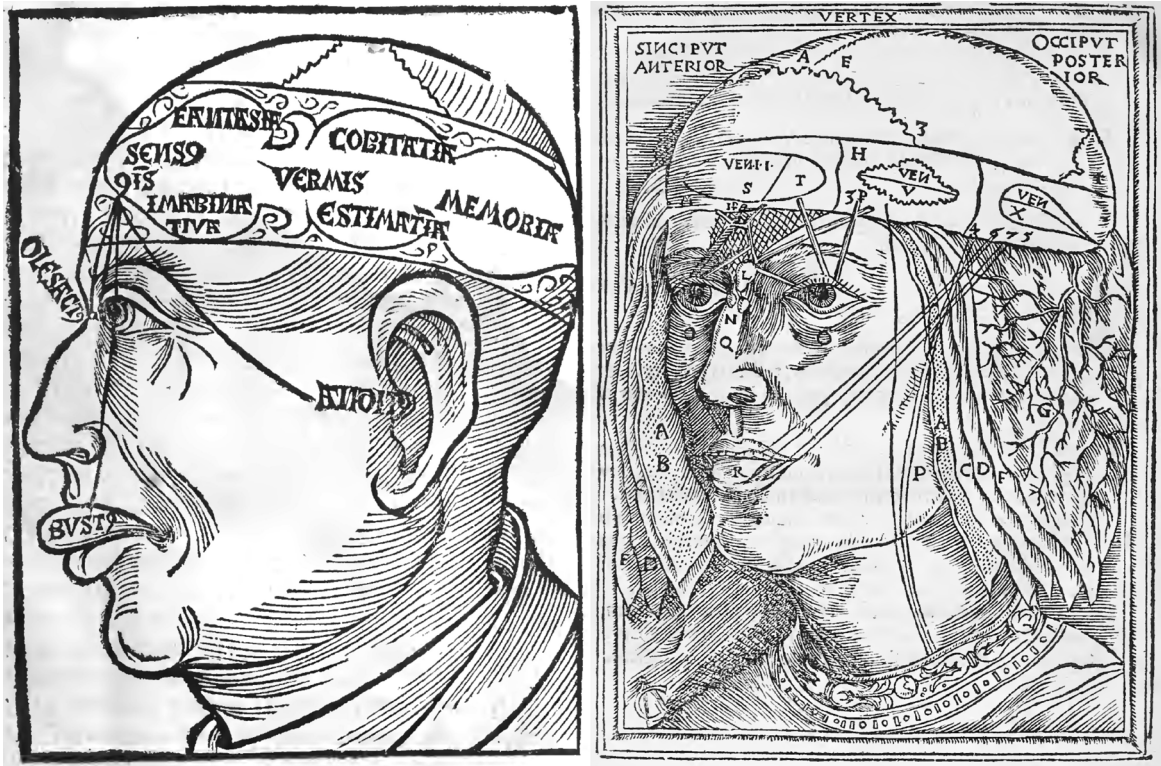
Since time immemorial, humans have enquired about two essential aspects of psychic activity: its location (structural placement; the “where”) and its functioning (mechanisms of action, the “how”).

For thousands of years, the answers to these questions arose within a framework of magical-religious thought that considered human activity to be mediated by the action of higher forces or entities. This tendency began to lose prominence around the sixth century BC, with the beginning of a shift from magical-religious thought to a materialist approach that situated psychic life in

the heart (cardiocentric model) or in the brain (encephalocentric model). Thanks to the contributions of Hippocrates (ca. 460-370 BC) and Galen (130-200 AD), the encephalocentric model eventually won out over the cardiocentric paradigm.<sup>A</sup>

Regarding the functioning of psychic activity, Galen proposed that brain function was the result of animal spirits (*spiritus*, the Latin translation of the Greek *pneuma*). This substance, stored in the brain ventricles, flows

<sup>A</sup>In the Middle Ages, despite the pre-eminence of the encephalocentric model, such authors as Hildegard of Bingen (1098-1179), Doctor of the Church, continued to argue that the heart was the seat of psychic life.



**Figure 1.** Left: the medieval ventricular doctrine, depicted by Hieronymus Brunschwig (ca. 1450 - ca. 1512).<sup>3</sup> Right: the connection between the cerebral ventricles and the sensory organs, according to Johannes Dryander (1500-1560).<sup>4</sup> Motor control of speech is represented by lines 6 and 7, which originate in the movement part of the posterior cell and connect directly with the lips. Line 4 and pathway P represent the motor control of the rest of the body. The cross-hatched area above the eyes is the *rete mirabile* ("wonderful net"). The human *rete mirabile* is a medieval invention inherited from such classical anatomists as Herophilos and Galen, who (erroneously) imagined that certain structures present in numerous animal species also existed in humans.

to the muscles through hollow tubular structures (nerve fibres).<sup>1</sup> According to this theory, movement results from the expansion of muscles after animal spirits enter them (a mechanism resembling the inflation of a balloon). This proposal became the standard pattern for explaining brain physiology for over 1500 years.<sup>B</sup>

In the late fourth century AD, Nemesius of Emesa, Posidonius of Byzantium, and Augustine of Hippo, the first fathers of the Eastern Christian Church, asserted that intellectual faculties *reside* in the cerebral ventricles and not in the solid parts of the brain (the so-called ventricular doctrine) (Figure 1).<sup>2-4</sup> Medieval understanding of the nervous system was based on adhesion to concepts

from classical medicine; these were confirmed in various ways, and never modified or questioned, with the direct study of nature and the human body taking a back seat. The perpetuation of this doctrine throughout a large part of the Middle Ages was facilitated by the prohibition of brain dissections. This situation gradually changed over the course of the 14th century, with the recovery of post mortem examinations and the incorporation of new discoveries about the anatomy of the cerebral ventricles. These discoveries contributed decisively to the transition from classical/medieval conceptions to modern thought.<sup>2</sup>

The 17th century saw the rejection of classical dogmas about neuroanatomy and neurophysiology (the ventricular doctrine and animal spirits) and their progressive replacement with concepts that are more aligned with anatomical and physiological facts. In this context,

<sup>B</sup>Galen's theory of animal spirits is based on the concept of *pneuma psychikon* (psychic pneuma), postulated by Herophilos in the third century BC.



**Figure 2.** Illustrations of the cerebral cortex from the 16th and 17th centuries. Note the undifferentiated appearance and the random distribution of gyri. From left to right: *Anatomiae* (1537) by Johann Dryander (1500-1560),<sup>4</sup> *Tabulae anatomicae* (1632) by Giulio Cesare Casseri (1552-1616),<sup>5</sup> and *Neurographia universalis* (1685) by Raymond de Vieussens (1641-1715).<sup>6</sup>

some researchers proposed that the cerebral cortex was the biological substrate of psychic processes (corticocentral paradigm) (Figure 2).<sup>4-6</sup> Until that time, the prevailing wisdom had been that the cortex lacked any function, and played a merely protective role; this explains its name, derived from the Latin *corticea* (crust, bark).

This study aims to summarise the main milestones of the transition from the ventricular doctrine to the corticocentral doctrine in the 17th and 18th centuries. To that end, we refer to the original works cited in the references section wherever possible.

## Development

### *Seventeenth century: twilight of the classical dogmas*

In the 17th century, Galen's animal spirits continued to be the main theory for interpreting the physiology of the brain. However, some voices began to question whether these spirits *resided* in the cerebral ventricles. In *Theatrum anatomicum* (1605), the Swiss physician Caspar Bauhin (1560-1624) argued against the idea that the animal spirits may be created and stored in these structures. Bauhin believed that the animal spirits were generated in the brain parenchyma and, from there, were distributed through the nerves to the sensory organs and the muscles responsible for movement.

He argued that the ventricles had no other purpose than receiving waste and residues from the brain's nutrition and the production of animal spirits. These ideas were supported by Caspar Hoffmann (1572-1648) and Johann Wepfer (1620-1695), among others.

In 1634, Franciscus Sylvius (1614-1672) (Figure 3) drafted a brief dissertation to obtain his medical degree.<sup>8,9</sup> In the document, he argues that animal spirits are generated both in the cerebral ventricles and in the parenchyma. Three decades later, in the fourth part of his work *Disputationum medicarum*, published in 1663,<sup>10</sup> Sylvius asserted that animal spirits are distributed through the nervous system by a transport system similar to that proposed by William Harvey to explain the circulation of the blood.<sup>c</sup> He suggested that the cerebral and cerebellar cortices act in conjunction to separate and purify the animal spirits in the blood; the watery part remaining from the blood formed the ventricular and meningeal fluids. Subsequently, these spirits are transported to the white matter and nerves. If they are not fully consumed at these levels, they are drained into the lymph vessels and returned to the bloodstream.

<sup>c</sup>In 1628, William Harvey (1578-1657) suggested that the blood could be reused, thanks to a closed circulatory system enabling its recycling.





Figure 3. From left to right: Franciscus Sylvius (1614-1672), Thomas Willis (1621-1675), and Marcello Malpighi (1628-1694).

The idea sketched out by Sylvius was further developed by Thomas Willis (1621-1675) (Figure 3) in his work *Cerebri anatome* (1664).<sup>11</sup> Willis asserts that the brain parenchyma is the seat of the rational human soul, imagination, and memory. Specifically, he suggests that the animal spirits are created in the surface of the brain, or cortical substance, whereas the medullary substance is responsible for their functioning and distribution.<sup>D</sup> Regarding the ventricular doctrine, he writes that: “The Ancients have so magnified this Cavern, that they affirmed it the Shop of the animal Spirits, both where they themselves were procreated, and performed the chief works of the animal Function. [...] But indeed that opinion of the Ancients is easily overthrown, for

that the animal Spirits, being very subtil, and apt to fly away, require not such large and open spaces, rather than the more narrow passages and little pores, such as are made in the substance of the Brain.”<sup>12(p96)</sup>

Willis’ disruptive proposal was supported by other physicians of the day. In 1666, Marcello Malpighi (1628-1694) (Figure 3) published his work *De viscerum structura exercitatio anatomica*,<sup>13</sup> which included the treatise *De cerebri cortice*. In the text, he writes that:

The cortex is formed from a mass of very minute glands. These are found in the cerebral gyri which are like tiny intestines and in which the white roots of the nerves terminate or, if you prefer, from which they originate. They are so exactly fitted to one another that their mass forms the surface of the brain.<sup>14(p87-88),E</sup>

In another passage, he suggests that these cortical glands are the starting point of long, thin channels filled with a fluid (made up of the animal spirits) (Figure 4).<sup>15</sup> In *Neurographia universalis*,<sup>6</sup> Raymond de Vieussens

<sup>D</sup>Willis’ writings differentiate between the cortical and the medullary substance. The latter corresponds to what is today known as white matter.

<sup>E</sup>Translator’s note: translation from the original Latin by C.D. O’Malley, printed in: Clarke E, Bearn JG. The brain “glands” of Malpighi elucidated by practical history. *J Hist Med Allied Sci*. 1966;XXIII(4):309-30.



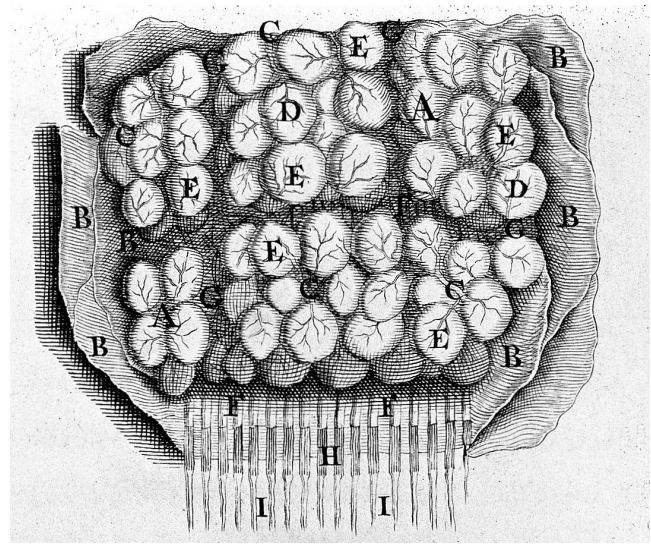
(1641-1715) argues that the animal spirits are produced and distributed by the grey matter of the brain.

Animal spirits *migrate* to the cerebral cortex following their expulsion from the ventricles. In parallel, some voices began to question the existence of the animal spirits and their value in explaining brain physiology. Giovanni Borelli (1608-1679) proposed that the nerves are not empty conduits through which the animal spirits flow, but rather channels filled with a spongy material moistened with a spirituous juice (*succus nervus spirituosus*) that transmits waves.<sup>16</sup> While the notion of a wave resemble today's understanding of nervous transmission, Borelli continues to accept the concept of animal spirits, in the form of this *succus nervus*. Corneille Bontekoe (1647-1685) believed that "the ancients, and the majority of the moderns, imagined that animal spirits existed. But, after natural and vital spirits dissipate, we believe that animal spirits must also disappear."<sup>17(p105)</sup> In another passage, he explains how: "Regarding Willis' opinion [about brain physiology], this is rather absurd and brings with it the grossest errors of paganism. [...] which in this century constitutes the confession of a shameful ignorance that merits no reply."<sup>17(p156)</sup> The experiments of Jan Swammerdam (1637-1680)<sup>18</sup> and Francis Glisson (1597-1677)<sup>19</sup> contributed to demonstrating that animal spirits did not exist, and therefore had no role in nervous transmission and muscle movement.<sup>F</sup>

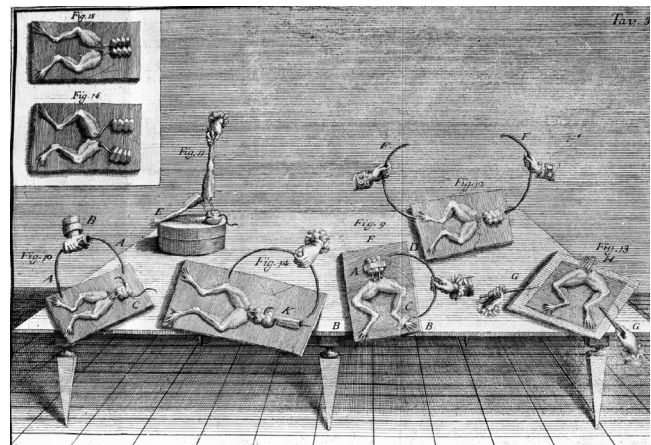
#### *Eighteenth century: prelude to a new era*

Over the course of the 18th century, the ventricular doctrine lost support and there was general acceptance of the idea of the cerebral cortex as the seat of psychic life. However, some authors, such as Thomas von Sömmerring (1755-1830), continued to defend the theory of the cerebral ventricles as the seat of the mind.<sup>20</sup> The animal spirit doctrine met a similar fate, and was replaced in the latter third of the 18th century by the animal electricity theory of Luigi Galvani (1737-1798) (Figure 5).<sup>1</sup> During the transition from animal spirits to animal electricity, the basis of today's neurophysiology, creative proposals were set out that attempted to explain the functioning of the nervous system.

<sup>F</sup>Swammerdam and Glisson conducted their work within the framework of the experimentalist movement led by such figures as Francis Bacon (1560-1626) and Galileo Galilei (1564-1642).



**Figure 4.** Depiction of the cortical glands described by Malpighi. Illustration taken from the work *Anatomia humani corporis* by Govard Bidloo (1649-1713).<sup>15</sup> Malpighi's work *De cerebri cortice* includes no drawings of the cerebral cortex.



**Figure 5.** Some of the methods analysed by Galvani to generate muscle contractions in frog legs using electric discharges (plate 3, *De viribus electricitatis in motu musculari*; 1791).

In 1755, the influential physiologist Albrecht von Haller (1708-1711) published his work *A dissertation on the sensible and irritable parts of animals* (Figure 6).<sup>21</sup> This text is an *update* of the old neurophysiology, substituting the classical animal spirits with the *vis nervosa* (in fact, this is the same concept but with a different name). Von Haller suggests that the nerves possess a force (*vis nervosa*) that triggers muscle contraction, or transmits

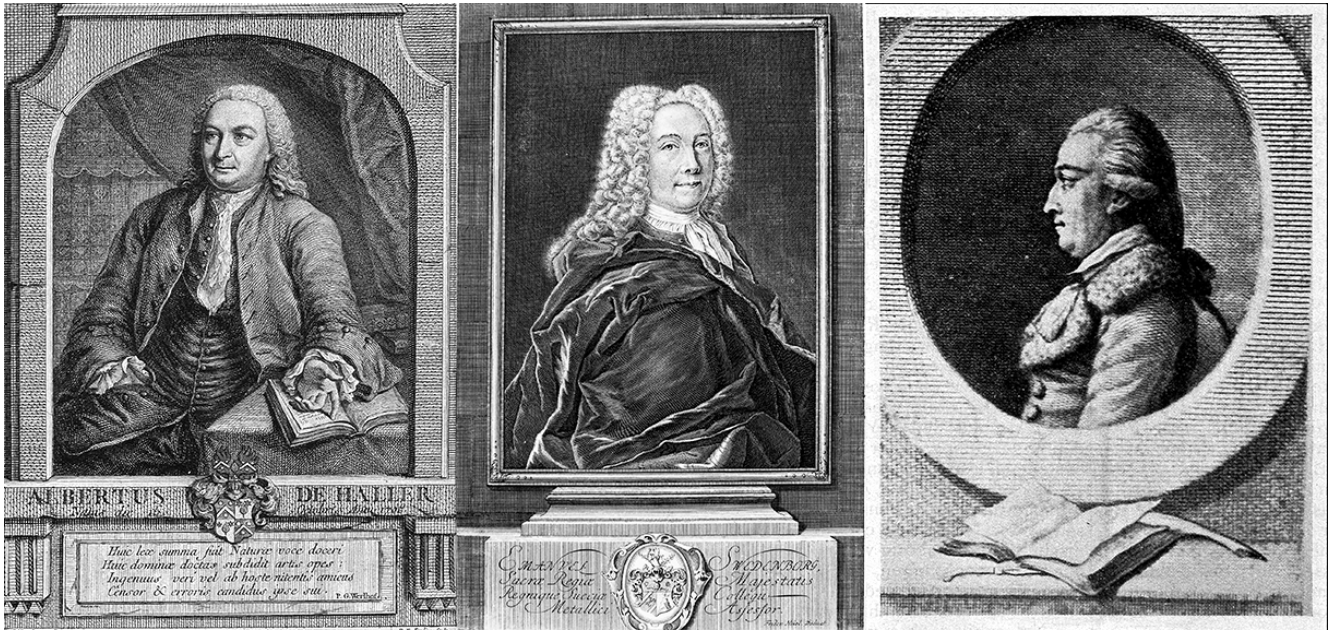


Figure 6. From left to right: Albrecht von Haller (1708-1777), Emanuel Swedenborg (1688-1772), and Georg Procházka (1749-1820).

sensory information to the brain. In an experimental theory, von Haller divided the organs of the body into irritable (eg, muscles) and sensitive organs (eg, the sensory organs and the nerves). With respect to the nervous system, he tested the sensitivity of numerous cerebral structures with mechanical, electric, and chemical stimuli. The cerebral cortex always appeared insensitive, regardless of the region stimulated. This finding led him to conclude that the cortex was insensitive and equipotential. Due to his academic prestige and his numerous contacts and sympathisers, von Haller's ideas were treated as dogma by the scientific community until well into the 19th century.<sup>22</sup>

In 1774, von Haller published the second volume of his *Bibliotheca anatomica*,<sup>23</sup> in which he referred to the treatise *Oeconomia regni animalis* (1740) by Emanuel Swedenborg (1688-1772) (Figure 6).<sup>6</sup> Like Sylvius and Willis before him, Swedenborg believed that the cerebral cortex was associated with thought, reason, and will.

However, he went a step further than his predecessors, positing that the cortex was made up of specialised regions (*cerebellula* or *spherule*) that were responsible for different functions. Citing the available anatomical and histological data, he concluded that the *cerebellulas* were functionally autonomous units responsible for psychic processes:

If [the anterior] portion of the cerebrum therefore is wounded, then the internal senses—imagination, memory, thought—suffer; the very will is weakened, and the power of its determination blunted [...]. This is not the case if the injury is in the back-part of the cerebrum.<sup>24(p73)</sup>

While Franz Joseph Gall (1758-1828) is habitually afforded the merit of being the first to propose cortical functional localisation, it would be fairer to grant this

<sup>6</sup>Emanuel Swedenborg's name is strongly associated with the New Church, an ecclesiastical organisation established in 1787 according to the precepts included in Swedenborg's mystical writings.



honour to Swedenborg.<sup>11</sup> In any case, Gall was the first to develop a theory of the functioning of the cerebral cortex based on its functional compartmentalisation. Swedenborg's ideas mark a rupture from the received wisdom of the day, and their methodological foundation is more robust than that used decades later by Gall. Whereas Gall localised psychic faculties arbitrarily, through palpitation of the skull, Swedenborg based his hypothesis on the analysis of clinical/pathological data collected by the researchers of the day. Nevertheless, Swedenborg's view of nervous system physiology was not so groundbreaking, and was well aligned with contemporary understanding. He maintains that animal spirits are the most plausible mechanism for explaining the functioning of the nervous system, and that they are produced in the cortical glands described by Malpighi.

In 1779, Georg Procházka (1749-1820) (Figure 6) published *De structura nervorum: tractatus anatomicus*,<sup>25</sup> in which he reformulated von Haller's concept of *vis nervosa*. With reference to Isaac Newton's force of attraction (*vis attractiva*), Procházka postulated that the nervous force (*vis nervosa*) is an elemental form of energy that is only observable through its effects, and that its manifestation requires an excitatory cause (stimulus).<sup>26</sup> In other words, he suspected that nervous force was a property of the fibres, and not something flowing through them.

In the book, Procházka also presented his conjectures about the anatomical localisation of psychic life (Figure 7):

It is, therefore, by no means improbable, that each division of the intellect has its allotted organ in the brain, so that there is one for the perceptions, another for the understanding, probably others also for the will, and imagination, and memory, which act wonderfully in concert and mutually excite each other to action.<sup>25(p447)</sup>

Likewise, he suggests that "the organ of the imagination, however, amongst the rest, will be far apart, I should think, from the organ of perceptions, since the organ of perceptions being asleep and at rest, the organ of the imaginations may be in action, a condition which produces dreams."<sup>25(p447)</sup> From these words, we may glimpse the presence of Gall's theory of the plurality of cortical organs, in a very embryonic form, in Procházka's work.

<sup>11</sup>This incorrect attribution probably owes to a lack of knowledge of Swedenborg's texts among many 19th-century researchers. It was not until 1901 that Max Neuburger (1868-1955) rescued Swedenborg's writings from obscurity, reclaiming the Swedish scientist's role in the history of medicine.

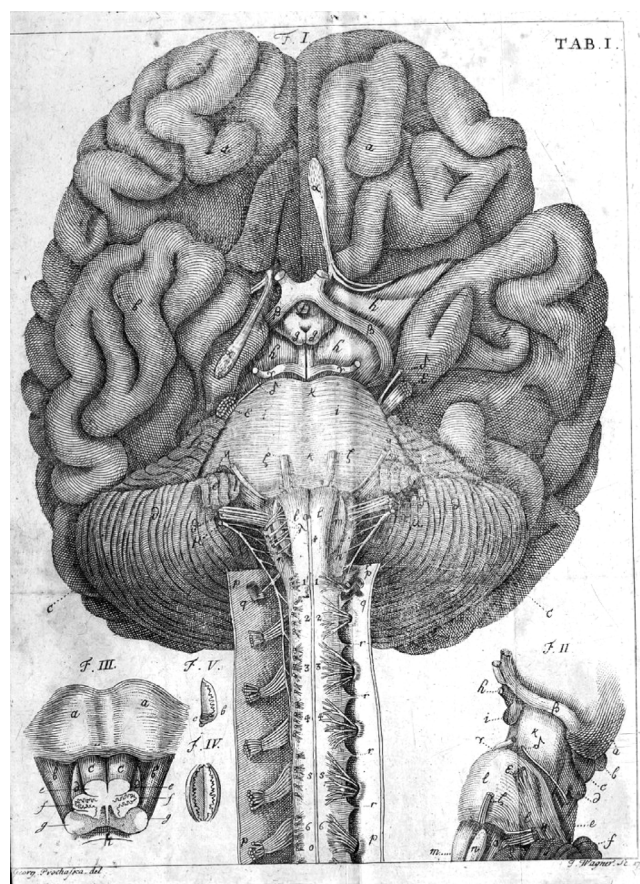


Figure 7. An illustration of the brain, cerebellum, and brainstem, taken from *De structura nervorum* (Procházka, 1779).

### The dawn of cortical localisationism

The medical/scientific thought of the 18th century interpreted the cerebral cortex as a unified structure that could not be divided into differentiated functional parts. In this context, discordant views emerged, such as those of Swedenborg and Procházka, who heralded the advent of a new era in the study of cortical function. This era was inaugurated by Franz Joseph Gall with his *Schädellehre* ("skull doctrine").

In the late 18th century, Gall proposed that, just as the body contains organs associated with specific physiological functions, the cerebral cortex is also made up of mental organs, each of which is dedicated to a specific task.<sup>27</sup> He supported these ideas by analysing prominences on the skull (cranioscopy) and deducing the

functional roles of different cortical regions. Despite its erroneous ideas and methods, *Schädellehre* (subsequently known as phrenology) led to a reconsideration of cortical physiology. In 1825, Jean-Baptiste Bouillaud (1796-1881), with Gall's texts as a reference, argued that the organ of articulate language is situated in the anterior lobes of the brain.<sup>28</sup> This view collided head-on with the theories of the French physician Marie-Jean-Pierre Flourens (1794-1867), who considered the cerebral cortex to be homogeneous and equipotential (with all cortical regions participating in mental functions, acting as a whole).<sup>29</sup> It was not until the 1860s that Paul Pierre Broca (1824-1880) provided the first documented, empirical evidence of the correlation between a cognitive process and a specific cortical region. Specifically, he suggested that the left third frontal gyrus was the neuroanatomical substrate of articulate language.<sup>30,31</sup> Shortly thereafter, in 1870, Eduard Hitzig (1838-1907) and Gustav Theodor Fritsch (1838-1927) linked posterior regions of the frontal lobe to the production of specific movements.<sup>32</sup> This finding, together with Broca's, generated the necessary impetus for a multitude of researchers and physicians to become interested in studying the functional organisation of the cerebral cortex.<sup>33</sup>

## Conclusions

Over the course of history, different solutions have been proposed to unravel the anatomical location of psychic activity and the mechanisms through which its activity occurs. For centuries, the ventricular doctrine and the theory of animal spirits were the standard conceptual framework explaining the anatomy and physiology of the brain. The 17th and 18th centuries constitute a period of transition from classical/medieval to modern medical thought. Authors including Caspar Bauhin, Johann Wepfer, Thomas Willis, and Marcello Malpighi asserted that the cerebral cortex was the seat of psychic life. Emanuel Swedenborg and Georg Procháska went a step further, suggesting that the cerebral cortex was made up of specialised functional regions; these ideas constituted the precursor to the cortical localisationism of the 19th century.

## Conflicts of interest

The authors have no conflicts of interest to declare. This study has received no public or private funding.

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