

REFLECTION PAPER

DOI: <http://dx.doi.org/10.15446/revfacmed.v66n2.62012>

From animal spirits to scientific revolution in Medicine (first part)

De los espíritus animales a la Revolución científica en medicina (primera parte)

Received: 17/01/2017. Accepted: 04/04/2017.

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| Abstract |

Introduction: Back in the sixth century BC, as part of the evolution of Medicine, a philosophical idea was proposed to explain how the nervous system works based on elements known as animal spirits, considered for many centuries as transmitters of sensation and movement. This philosophical concept, with a speculative basis, prevailed until the seventeenth century with subtle changes, but was later outweighed by demonstrative advances in neurophysiology.

Discussion: Dogmatic tradition dictated for centuries that the animal spirits that controlled body actions were transmitted through the nerves; however, with the scientific revolution, such ideas were changed by better elaborated concepts supported by the scientific method.

Conclusion: The old concept of the functioning of the nervous system changed radically after the seventeenth century, when knowledge on morphophysiological characteristics of the nerves was expanded, opening new doors in search of more coherent explanations detached from any religious influence.

Keywords: Medicine; Science; Nervous System (MeSH).

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Barco-Ríos J, Duque-Parra JE, Barco-Cano JA. From animal spirits to scientific revolution in Medicine (first part). Rev. Fac. Med. 2018;66(2):233-6. English. doi: <http://dx.doi.org/10.15446/revfacmed.v66n2.62012>.

Introduction

Several bibliographical sources consulted since the sixth century BC until the seventeenth century mention ideas and philosophical concepts that were used in the past to explain the functioning of the nervous system and how the transmission of information through the nerves to control body actions was conceived.

A special type of cells, known as neurons, which are found in the nervous system, was discovered in the nineteenth century of our

| Resumen |

Introducción. En el desarrollo de la medicina, a partir del siglo VI a.C., se planteó una idea filosófica para explicar el funcionamiento del sistema nervioso con base en elementos conocidos como espíritus animales, considerados durante muchos siglos como agentes transmisores de las sensaciones y del movimiento. Este concepto filosófico de base especulativa prevaleció hasta el siglo XVII con sutiles modificaciones, pero después fue superado mediante demostración con los avances logrados en neurofisiología.

Discusión. Por tradición dogmática se aceptó durante muchos siglos que a través de los nervios se transmitían espíritus animales que controlaban las acciones corporales. A partir de la Revolución científica tales ideas cambiaron por conceptos mejor elaborados con apoyo del método científico.

Conclusión. El concepto que se tenía antiguamente sobre el funcionamiento del sistema nervioso cambió de forma radical a partir del siglo XVII con la ampliación del conocimiento de las características morfofisiológicas de los nervios, abriendo nuevas puertas en busca de explicaciones más coherentes y desligadas de cualquier influencia religiosa.

Palabras clave: Medicina; Ciencia; Sistema nervioso (DeCS).

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era, but some elements and concepts related to them were already conceived since ancient times. According to historical sources, Alcmaeon of Croton, philosopher, naturalist and doctor, of whom there are no reports regarding his date of birth and death, is considered to be the first to propose, at the end of the sixth century BC, that psychic functions had their seat in the brain. (1,2) He reached this conclusion based on clinical observations and experimental work on the intimate connection that sense organs have with the brain through communication channels or “pores” through which

sensations circulate. He also conducted detailed studies of the eyes and discovered the origin of the optic nerves. For Alcmaeon, the brain was the central organ where all sensory and psychic activities resided (3,4), therefore, it was the place where consciousness, sensations and understanding resided as well. (1)

A few years later, Hippocrates (460-371 BC), a famous physician born on the island of Cos, proposed the existence of three spirits (*pneumas*) to explain the general physiology of the human body. These three spirits (natural or vegetative, vital and animal) (5) impelled its functioning. This idea of the spirits was also supported by some Dogmatists such as Satyrus, Stratonicus, Aeficianus and Aeschriion, a follower of the Empirics. All of them thought that the diseases of the body depended on alterations of the *pneuma*. (6) At the time, physiology conceived the spirit as a special form of matter that put organs into operation.

So, Hippocrates thought that animal spirits, which are superior to the other two, came from the outside air and were taken to the brain to induce the development of intelligence (5), and that the brain was the seat of the soul. (7) Hippocrates also developed the theory of the humors, in which he reflected his belief that the body was composed of four fundamental humors: blood, phlegm, yellow bile and black bile. (8,9) Based on these postulates, Aristotle (384-322 BC) explained that the sensations of the body and those coming from the outside world were transmitted by the animal spirits in the form of vibrations, and that such spirits were light particles that moved like the wind through the blood, circulating from the heart to the brain and muscles to connect finally with the soul or vital principle, located in the pineal gland. (5)

In another part of the world, around this time, the ancient Egyptians had a similar idea. They believed that three entities were released at the time of death: the Ka, the Ba and the Akh. For the Egyptians, the Ka was the life force of the individual and was related with food intake; since humans need to eat to sustain life, food was necessary even beyond death. The Ba is what transcends, the soul; while the Akh is the luminous body. (10)

Later, Herophilus of Chalcedon (335-280 BC), renowned physician of the court of King Ptolemy II and professor in Alexandria and considered as the first anatomist to perform anatomical dissections in public, (11) made important anatomical findings, and also practiced vivisections in criminals who had been sentenced to death. (12,13) Some of these findings relate to the differences between the brain and the cerebellum, which led him to state that intelligence was located in the brain (2) and not in the heart, as Aristotle had previously proposed. He also differentiated the blood vessels and the tendons of the nerves (3,14) and classified the latter into sensory and motor nerves. Additionally, he proposed a theory about the functionality of animal spirits in which *pneuma zoticon* (*spiritus vitalis*), found in the blood, was transported from the heart to the brain and transformed in the lateral ventricles into *pneuma psykhhikon* (*spiritus animalis*) (15-17), spirit responsible for life functions, to travel through the nerves to the muscles. (18,19)

Erasistratus of Cos (304-250 BC), Herophilus's contemporary, although a little younger than him, was a Greek physician and anatomist considered to be the forefather of neurophysiology. Together with Herophilus, he founded the Alexandria School of Medicine and developed a new anti-hypocritical physiology. (20) Some of his most important contributions include the characterization and differentiation of the anterior and posterior horns of the spinal cord and their role in sensibility and motor skills, and in the distribution of the brain gyri in different species and their connection to the degree of intelligence. He also demonstrated the solid tubular structure of the nerves, which were not hollow, as was believed at that time,

and that animal spirits were transported through them to allow control of muscle movement. (21,22) Erasistratus concluded that the coordinating center of psychic life was located in the cerebellum and the meninges. (20)

Although the Greek physician Galen of Pergamon (130-201 BC) made important anatomical contributions through dissections, after analyzing the nervous system and observing that it occupied the central region of the organism, he proposed that the brain controlled all other organs, and even demonstrated that the muscles were controlled by different levels of the spinal cord through a network of hollow nerves organized in two ways, one coming from the senses and another that allowed to perform all physical actions. (6)

Nevertheless, the thought of Galen was strongly influenced by old philosophical ideas, like the doctrine of the three spirits proposed by Philolaus of Croton (449-350 BC). When he explained how the brain exerted control, he affirmed that everything began with food intake and that the product of digestion was taken from the intestines to the liver where it was used to create the natural spirits. Natural spirits were then taken to the right side of the heart, where they were transformed into vital spirits. Then they were carried by the blood to the cerebral ventricles where, finally, they were converted into animal spirits. (23)

According to Galen, animal spirits propagated through the nerves to control the body. (24) This is the first known hypothesis that attempts to explain what is known today as nerve transmission; this theory was valid for more than 1 500 years without undergoing almost any modification; and then came an era of obscurantism, linked to little research and generation of new ideas. Mondino de Luzzi (1270-1326), in his book entitled *Anathomia corporis humani*, written in 1319, preserved the idea that the brain is divided into three vesicles (25) and proposed, as a new element, that the choroid plexus was the vesicle that regulated the flow of *spiritus animalis*. (26)

By the end of the Middle Ages and during the Renaissance, despite Leonardo da Vinci (1452-1519) and Andreas Vesalius (1514-1564), two brilliant anatomists, it was accepted, without further questioning, that the animal spirits that controlled the body were transmitted by the nerves. Through dissections carried out on executed criminals, Vesalius reached conclusions that contradicted established Galenic dogmas. He noticed, for example, that the structure of the brain was quite different from that proposed by Galen and that the cerebral vesicles did not contain *spiritu*, but were filled with a clear fluid: cerebrospinal fluid.

In turn, Leonardo da Vinci gave great importance to cerebral vesicles by stating that, in addition to playing a receptive and analytical role, they had a dynamic function, since they transmitted the orders for movement and human emotions. Da Vinci thought that a system of nerve pipes arose from the spinal cord through which motor impulses were transmitted to the peripheral regions of the body, and that the animal spirits that carried the sense of touch were transported through such pipes to the vesicles for processing. (27)

However, despite questioning that the nerves were not hollow, Vesalius said that they served to carry animal spirits. (28) It is believed that this thought was more related to the fear of questioning religious ideas than to his scientific conviction. At least that is deduced from the following words: "I will refrain from considering the divisions of the soul and its location, since today many censors of our very sacred and true religion can be found." (29)

During the Scientific revolution, between the sixteenth and seventeenth centuries, new ideas and knowledge emerged in the scientific world that completely transformed the ancient conceptions about nature, based largely on speculation and deduction. This transformation of scientific thought was driven mostly by René Descartes (1596-1650), a leading French philosopher, mathematician

and physicist. In his work entitled *Discourse on the method*, he defined the rules that the method should have to “rightly conducting one’s reason and seeking truth in the sciences.” (30) Descartes also proposed that the pineal gland was not only the material support of the divine spirit, but was responsible for the correct communication between the human machine and its environment. (31) He stated that the cerebrospinal fluid that filled the brain vesicles was under pressure and that when the mind decided to perform an action, the pineal gland turned in a particular direction. In this way, he linked the movement of the cerebrospinal fluid, which traveled from the brain to the nerves, with the genesis of movement (32), thus facilitating the distribution of animal spirits. (33)

Although Descartes influenced scientific thinking, he retained the idea of the *spiritus animalis* of his predecessors. (34) His contemporary, Niels Stensen (1638-1686), refuted this thesis and, by means of a careful dissection, revealed the correct position of the pineal gland, showing that it was a fragile structure fixed on the diencephalon and that it tended to break easily when it moved, therefore, it could not produce movements. (33)

Starting with Descartes, new knowledge had to be supported with the scientific method in order to reject ancient paradigms. For example, in the field of anatomy, Thomas Willis (1621-1675) made important contributions: he classified the cranial nerves into nine pairs (35), described the thalamus of the mammillary bodies, the arborescent arrangement of the gray and white matter of the cerebellum and the circulation of the brain with the classical figure of the polygon, which later took his name. (36) This allowed ending with Galen’s paradigm of the *rete mirabile*. However, in the field of physiology, Willis made an unforgivable mistake and fell into speculations, as he continued to support the theory of animal spirits, stating that they were formed in the brain by distillation from arterial blood and then went down the nerves to the organs, where they acted as agents of sense and movements. (37)

Finally, in the seventeenth century, Galen’s hypothesis began to be dismantled with the help of rudimentary microscopes that allowed establishing, by observing histological preparations of the nerves, that such structures were not hollow. At the same time, Giovanni Alfonso Borelli (1608-1679), physicist and mathematician who applied his knowledge to physiology, tried to solve his doubts about the presence of animal spirits as generators of muscular movement. For this purpose, he designed an experiment in which he submerged one of the limbs of an animal in water and then cut a muscle to see if *pneumas* came out of the wound in the form of bubbles. As he did not see any reaction, he concluded that such spirits did not exist and proposed a second hypothesis to explain the mechanism of muscular contraction, which explained that it was generated by the fermentation of some substances. (38)

Discussion

The magical and speculative thinking that prevailed in the past resulted in the formulation of explanations based on false cause-effect relationships. Such ideas were unsuccessful considering the falseness of the precepts on which they were founded. They spoke about phenomena in a superficial manner and lacked operating force in the world of reality. (39) The tradition of keeping ideas as dogmas has prevailed throughout the history of mankind, but this thought has switched from demonstration to experimentation over time, which is an intelligent theoretical-practical exercise. (40) Hence, at first, science advanced slowly due to irrational conceptions and postulates (10) such as animal spirits to explain the transmission of nerve impulses. Science gives us solid and real support taken

from evidence, separating itself from religious dogmas that avoid reflection and intelligent analysis (40), as was the case of Vesalius (29), so ideas are based on reality and are not the result of mere speculative reasoning.

In the field of physiology, the concept of animal spirits as entities that emerged from the air and were transported to different parts of the body—conducting sensory information and allowing cognitive processes—was the result of the speculative reasoning that lasted until the seventeenth century, when the scientific revolution occurred. With the implementation of the scientific method applied to morphological investigations, it was possible to start proving that the nerves were not hollow structures in the way that Galen had described. (6) The physiological studies by immersion of body parts performed by Borelli (38) strongly refuted the idea that prevailed at that time in relation to the presence of animal spirits, as gaseous entities, that traveled through the nerves to generate movement.

This whole thought of revolution allowed creating a new intellectual and academic environment that was evident in almost all areas of knowledge, leading to the emergence of new theories and concepts that could be explained by experimental demonstration, more adjusted to the reason. All this made possible the development of new and better techniques of experimentation in the field of physiology easier, which allowed giving an increasingly coherent explanation to the phenomenon of nervous transmission. Finally, history led us to the concept known today as action potential or nervous impulse. Therefore, we had to separate ourselves from metaphysical and religious doctrines to modify reality (39), and thus become aware of the way how the body communicates through the nervous system.

Conclusion

The idea of animal spirits was speculative and emerged at the dawn of medicine to satisfy the need to provide an explanation from the religious “rationality” to the physiological mechanisms that allow communication between the nervous system and the different parts of the body. With the advent of the scientific method and experimental demonstration in the field of physiology, complemented by morphological studies of the nerves, it was possible to separate medical science from religious thought following the scientific revolution of the seventeenth century.

Conflicts of interest

None stated by the authors.

Funding

None stated by the authors.

Acknowledgements

None stated by the authors.

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