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ARISTOTLE ON THE HEART AND BRAIN

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Abstract

'De Partibus Animalium' is a very significant part of Aristotle's work. There is strong evidence that in this work of Aristotle we find a simultaneous development of the zoological, biological and psychobiological issues which are significant for understanding the position of Aristotle biologist and philosopher. On the basis of the 'De Partibus Animalium' it will be demonstrated how Aristotle understands the biological dimension of the body. In the first part of this paper, the attention will be concentrated on role and function of the heart. In the second part, the focus will be on the brain. In the conclusion section, the main implications of the Aristotelian view of living beings and Aristotelian methodology in Biology will be summed up. The aim of this work is to examine the basic ideas of Aristotle as biologist and philosopher regarding the structure and functions of heart and brain.

Keywords: history of science, philosophy of biology, Aristotle, anthropology

1. Introduction - Why 'De Partibus Animalium'?

De Partibus Animalium (hereinafter *PA*) is a very significant part of Aristotle's work for two reasons. Firstly, in the first section, consisting of book I, is a general methodological introduction to the entire development of the biological Aristotelian thought. It can be said that with the book of the *PA* the biological thinking of Aristotle, at least in reference to his general theory of Biology, starts in fact from zero [1]. The second section of the *PA* (books II-IV) consists of a theoretical investigation of huge empirical data, also collected in the *Historia Animalium* (hereinafter *HA*). In fact the second section of the *PA* is focused mainly on the anatomical and morphological point of view, enriched by many references to physiological problems [1, p. 489-493; 2].

Secondly, the importance of the *PA* can be found in the fact that this work was probably developed during the same period as the ontological studies included in Aristotle's *Metaphysica*. Moreover, the *De Anima* (hereinafter *DA*) was probably prior to it, and the *De Generatione Animalium* (hereinafter *GA*) posterior [1, p. 486]. Thus among the biological works of *Corpus Aristotelicum* there are very significant and reciprocal interactions at the philosophical and

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scientific level of explanation. All these factors can be considered as strong evidence that in the *PA*, we find a contemporary development of the zoological, biological and psychobiological issues which are significant for understanding the position of Aristotle biologist and philosopher, and the foundation of his ideas regarding the problem of human soul and the human corporality [1, p. 487-488; 3; 4].

2. The heart

Very important in the thinking of Aristotle is the question of the relationship between the heart and the brain, which was for nearly two centuries in the centre of philosophical and scientific debate in the ancient Greece. In this debate two major currents of thought were presented [1, p. 543-549]. The first was accorded to Alcmaeon of Croton and his anatomical discoveries and the second to Empedocles. Alcmaeon was probably the first one who practiced dissection, which allowed him to discover the existence of channels (*poroi*), connecting the sensory organs with the brain. It is not surprising to find some concepts from Alcmaeon's epistemology in Aristotelian ideas, concerning the problem of connecting the reality of experience, knowledge and *techne*. But, contrary to Aristotle, Alcmaeon regarded the brain as the centre of perceptual and intellectual human activity.

Empedocles emphasized the importance of the blood, and therefore considered blood to be the seat of sensibility and thought. The reason for this came from the theory that the blood is made up of the mixture of the four elements (fluidity – the water, the heat – the fire, the density – the earth, the mobility – the air). In this way, Empedocles believed that there is a close affinity and immediate continuity between man and nature. Therefore, in Empedocles' approach there developed the idea of the progress of knowledge by analogy (analogical method), since, according to him, nature manifested itself as a unitary context, including in itself man and in any given experience the immanent analogical relations [1, p. 548; 5].

The philosophical and scientific context of research in the mid of 4th century BC provided Aristotle opportunity to consider the alternative of giving greater importance to role and function of the brain or of the heart. If one chose the brain, it became a choice of noetic structure of human knowledge, predominantly understood as the heuristic, inductive method of apprehension with a focus on the quantification of reality. On the other hand, choosing the heart did not mean to focus on the interpretative and hermeneutic character of knowledge, but rather to return to the manifesting force of reality, which reveals itself directly through the *phainomena*, expressed in the reality of what actually is [1, p. 549].

2.1. The levels of the composition of living matter

At the beginning of the 2nd book of the *PA* Aristotle presents his theory of the formation of living organisms that takes place on three levels of composition

[1, p. 540]. Firstly, there is the composition resulting from the so-called elements (*stoicheia*), namely earth, air, fire and water. But this idea is not only limited to the doctrine of *stoicheia*, but also extends itself to the active qualities (*dynámeis*: hot and cold, dry and moist).

In the *PA* Aristotle refers explicitly to the doctrine of the elements and the qualities, which originated in the Empedocles' doctrine of four elements, and was further developed in the writings of the syncretistic medicals from the late 5th and the beginning of the 4th century, and is also found in the Platonic Academy. Therefore, in the thought of Aristotle one finds influences from the *Timaeus*, but also from the medical school represented by Philistion of Locri. The latter being most probably the first to combine the doctrine of the elements with that of the qualities. Aristotle uses these ideas in the discussion in the *De Generatione et Corruptione* (II. 2-8), that consists in the statement that every natural body is composed of all the elements and of all the qualities (II. 8). In fact, he assigns to the four elements certain physical qualities, called the active properties (*dynámeis*). According to Aristotle, there are four qualities (hot, cold, dry, moist), and they must be coupled on the basis of the principle of opposites. But since the contraries cannot form a pair due to the principle of non-contradiction, the combinations of elements can only be four: hot-dry, hot-moist, cold-dry, cold-moist [6].

Therefore, according to Aristotle, the elements and the qualities they make lead to an emergence of a different *mixis* case by case, and the matter is going to be qualified according to the prevailing *dynamis* in *mixis*. Aristotle considers the states and the properties of matter as a transformation of *dynámeis* which is a step forward. This renewed conception of *dynámeis* allows him to break the schematic view of the elements-qualities, typical for the biological doctrines of ancient *physiologoi*. Aristotle wanted to consider these qualities in relative rather than absolute mode (*PA* 648b11). The theory of relativity of *dynámeis* leads to an exploration these qualities in the tactile properties of the bodies, namely in their capacity and the time needed for their heating, and in their capacity to be melted and combusted [1, p. 540-542; 7; 8]. In this way, according to the philosopher, the body parts were constituted of the elements, which transferred to each of the bodily parts the *dynámeis*. As a consequence, in the constitution of the different parts the proportions of the elements could vary, that is, each part could assume the predominant quality. These physical properties of a part were called *temperamentum* or *complexion* [6, p. 29-34].

The second level of composition constituted of the elements and qualities is the level of the uniform parts, such as bone, flesh and also to some extend the blood. The properties of these parts depend strictly on the elements-qualities prevailing in their composition. E.g. the blood is moist/hot, the bone is dry/cold. According to the philosopher the aggregation of the elements formed the simple and uniform parts, that, if decomposed or dissected, would provide smaller parts all equal between them and equal to the whole. As Aristotle explains: "Of the uniform parts present in animals, some are soft and moist, while others are hard and solid. Those that are moist are either generally so or are so while in their

natural setting, e.g. blood, serum, soft fat, hard fat, marrow, semen, bile, milk (in those that have it), flesh, and the parts analogous to these." (*PA* 647b10-11) The concept of uniform parts comes from Anaxagoras (*De caelo*, 302a) and was not limited to animals, but referred to minerals and plants, which are also made up of simple elements (*Met.*, IV 388a) [6, p. 24-25].

The third and the last level of the composition is that of non-uniform parts, such as face, hands, eye, nostril, entire arm and others (II. 1). In fact, different uniform parts could be aggregated and thus form a complex part (not-uniform), destined to different functions. Therefore the third level describes the parts that perform a specific function, and they are called *órgana* (*HA* 488b27-30). However, in general, the internal organs that perform a specific function (brain, lungs, heart, kidneys, spleen, liver), are called *splànchnon*, viscera. These *órgana* do not always correspond to organs in the modern sense. The hand, arm, face considered by Aristotle as the *órgana*, are not properly organs. It should be also mentioned that the heart is considered by Aristotle as belonging to both groups of bodily parts. The brain is not included by the philosopher in any of the two groups, because it "is neither a residue nor one of the continuous parts. Rather its nature is distinctive; and it is reasonable for it to be this way" (*PA* 652b2-6). It should be noted that the Aristotelian doctrine of uniform and non-uniform parts, adopted by Galen, remained in use until the late 18th century, with the difference, that the terms used by medieval and Renaissance authors to define the uniform and non-uniform parts were respectively *partes similares* and *dissimilares* [6, p. 25-28].

However, there should be added the last, definitive level of the composition – the body formed by the soul – that involves the aggregation of different organs to form the unity of the living body. Aristotle thought that the Platonic philosophers, and also his other predecessors, were not able to reach an appropriate theory of the soul of all living beings (*DA* 403b20ff.). The innovation of Aristotle consists in establishing the study of the soul as a general, biological science, that it has a foundational role for other special biological sciences. According to Aristotle the soul is not the body, but is what determines that the body is alive. It is the primary and essential determination of a body capable of living, equipped in organs suitable to perform the basic functions of life: nourishment and development (*DA* 412a3ff.). His application of the doctrine of the soul to the living makes clear that Aristotle admitted that most of the activities of the soul have a psychosomatic nature. An exception is human thought (*nous*) [9]. But the real element that connects souls with each other – the nutritive soul, sensitive and rational – is rather a kind of basic, vegetative functions of all livings. Aristotle also insists that the soul plays the causal role, namely the formal-final cause and the moving cause of the living being [10].

2.2. The heart as a passage from the material aggregate to the body structure

As already mentioned, Aristotle distinguishes three levels of the composition (*sunthesis*) of animals (*PA* 646a12). Therefore the elements supply

the matter (*hulē*) for composite bodies (*suntheton somaton*), while the uniform parts constitute the material basis for the non-uniform parts (*PA* 646a14ff.). Each level has its own characteristics and fulfils its own role to provide the causes of animal parts and their complex structures. Thereby Aristotle arrives at a question that could be formulated in this way: "is the development of a living organism the result of a sum of actualizations of element-potentials, or is it primarily the actualization of a single potential for an organism of that form, a potential the actualization of which involves the actualization of element-potentials, but is not reducible to them?" [11]. Up to this point the description of the genesis of the body remains incomplete.

To give an explanation of the entire body as an organic composite in its unity and totality (*organon*, *PA* 645b15ff.) Aristotle stresses that the elements are a necessary pre-condition for the uniform parts, and the latter are necessary pre-conditions for the non-uniform ones (*PA* 646b5-6). Thereby Aristotle states that the non-uniform parts represent the *telos*, a limit (*peras*) in the process of formation. Moreover Aristotle introduces a very important distinction between instrumental (*organikon*) and sensory (*aistheteron*) functions in animals (*PA* 647a3ff.). This distinction suggests that the instrumental parts are not homogeneous and that sensation takes place in the uniform parts (*PA* 647a4). Thus, according to Aristotle, the problem of bodily unity consists in the issue of the link between the sensory and the instrumental functions of body. This is so, because entire animals (*tois zôis holois*, *PA* 646b17) perform polymorphic (*polymorphon*) functions, and it is therefore necessary that the matter that composes them possess different properties (*dynámeis*, *PA* 646b15-17). Hence Aristotle's argument moves from the variability of functions and movements to the varied powers of elemental parts, which is designed to perform different functions. Now it is quite clear that the heterogeneity of functions is actually related to the heterogeneity of the material elements (*PA* 646b18). This shows the close link between inanimate and animate matter [12, 13].

However there remains the question how Aristotle wants to combine and link uniform (sensory) and non-uniform (instrumental) parts [13, p. 91-94]. It is in this context that Aristotle arrives at a crucial explanation for the problem of the heart. He notes that "since it is impossible to be an animal without perception, on this account too it would seem necessary for animals to have some uniform parts; for perception is in these, while actions are present through the mediation of the non-uniform parts" (*PA* 647a20-23). In the next lines of text (*PA* 647a24-31) the philosopher clearly shows an attempt to overcome the split between the homogeneous and non-homogeneous parts, between sensory and instrumental functions. The heart, or its analogous part, unites the body that would otherwise be divided into two parts. The heart, on the one hand is divided into uniform parts, but because of its shape (*morphê*) and configuration (*schêmatos*) it is non-uniform. In other words, the heart as a material part is divisible into homogeneous parts, but as a functional organ it is not divisible. Thus it can be said that Aristotle describes here a kind of proto-structural part of an intermediate nature. In a similar, proto-structural way he conceives of the veins (*phleps*) (*PA* 647b18-19).

According to him in one way the part of vein is homonymous with the whole uniform part (vein), but on the other hand it is not homonymous, because literally a part of a vein is not generally a vein (as the non-uniform). It means that proto-structural is a type of an intermediate nature between uniform and non-uniform parts somehow doubled as stuff and as structure. Now it is clear that the heart plays a central role in the problem of passing from the material level of the elements (mere aggregate) to the structural view of the animal body [7, p. 34-35; 12 p. 184; 14].

2.3. The heart as the principle of heat

The consideration of the heart as the natural principle is derived not only from the issue of passing from the matter of the elements (mere aggregate) to the structural view of the animal body, but also results from the physiological privilege of the heat itself. How does Aristotle demonstrate the role of the heart as a natural principle and as a seat of the heat? In the case of the heart as the source of blood, his proof included in the text *PA* 647a30-1 could be reconstructed as follows:

Premise$_1$) The heart is the origin of blood and is not present in bloodless animals.
Premise$_2$) Perception, movement, nutrition are present in all animals – blooded and bloodless.
Conclusion) So bloodless animals they must have an analogue of the heart [12, p. 184].

In the case of the heart as the seat of the heat J.G. Lennox proposes to reconstruct Aristotle's demonstration on the base of premises that come from the *Meteorologica* IV. 1-2, in the following way:

Premise$_1$) All growing things must take in nutrients.
Premise$_2$) All nutrients are derived from moist or dry material.
Conclusion$_1$/Premise$_3$) All growing things must take in moist or dry material.
Premise$_4$) Moist or dry material is transformed or digested (*pepsis*) into nutrients by heat.
Conclusion$_2$) So all growing things must have a source of heat [12, p. 198-199].

More precisely, what is the role of the innate heat? The idea that the animal heat could play an important role in biological functions had already been developed by Parmenides, Empedocles and other Hippocratic authors. For Aristotle, the heat was *sýmphyton*, that is, the innate or connate with the animal's life, and ensured the growth and nourishment of all living beings. It must be said that ancient theorists never raised the question as to how and according to what the innate heat had been originated. Therefore these explanations were far away from the idea that the heat comes from chemical reactions or cellular metabolism. Generally, in blooded animals, heat was thought to be responsible for digestion (*pepsis*), which is a series of chemical reactions that transformed food into blood. The last one was understood as a final nourishment for all parts of the body (*PA* 650a34). In this way the heart, as the natural seat of the heat, had the function of forming the blood (*HA* 520b10). The philosopher divides digestion in three

phases: the first, the mechanical process of chewing, then the second phase in the stomach, and the third in the ventricle of the heart (production of pure and sincere blood, *PA* 650a3-b10; *De Juventute et Senectute*, 469a1-5). Then Aristotle goes a step further, arguing that the principle of life, the heart with its innate heat, cannot have a different location from that of the principle that analyses sensations and produces movements (*De Juventute et Senectute*, 469a16-27). Therefore, for the philosopher an animal is characterized by vital processes and the ability to feel. The notion that the heart was the hottest viscera of the whole body, survived unchanged for nearly two millennia, until the experiment of Giovanni Alfonso Borelli in 1680, who by the use of the thermometer demonstrated that the temperature of the heart was not higher than other viscera of human body [6, p. 106-111].

2.4. The heart as a principle of perception and movement

In the *PA* we lack the systematic description of the nervous system conceived in contemporary terms, as opposed to descriptions of other systems. However, the heart plays the role of being the centre of perceptual activity (656a26-8; 666a34-5). In fact, as Aristotle observed, channels (*póroi*) are spread from the eyes and ears, which arrive at the veins around the brain, and from there the stimulus comes back to the principle, that is to the heart (656b16-20; cfr. *GA* 743b35-744a6). In his discussion on perception it can be seen that for Aristotle, at the functional level, the topographic contiguity of the channels had no decisive significance in the theoretical explanation of perception. Instead, he used the principle of the association of similar [4, p. 621; 15]. To understand this point it has to be mentioned that Aristotle, as some of his predecessors, associated the senses to the elements: water to sight, hearing and smell, respectively to air and to fire; taste and touch, considered as analogous, to earth. The logic of this association is explained in the different works (*De Sensu et Sensibilibus*, 438b18-439a1-5; cf. *DA* 425a5-15). In this way, the doctrine of senses associated with the elements was applied to the topography of the spatial relations between the sense organs and the brain or the heart [6, p. 73-75].

Aristotle demonstrated through dissections that the main sensors are connected to the heart thanks to the blood vessels (*phlébia*). Because his ancient predecessors did not know about nerves, the channels were called *póroi* or *phlébia*. Plato, Hippocratic physicians, Alcmaeon, Anaxagoras had indicated the brain as the seat of the arrival of all sensations. However it had not escaped Aristotle that Plato in *Timaeus* indicated that some feelings could come to the liver and to the heart (65d-66a, 67b). The teachings of Empedocles held that the blood is the instrument of perception and knowledge, and explanations of Diogenes of Apollonia also argued that sensations could spread throughout all the body by the *phlébes* [5, p. 627-629]. All these ideas formed the theoretical basis for Aristotle's thesis of the link between the sense organs and the heart. However, apart from the arguments of his predecessors, Aristotle was also performing many anatomical dissections, looking for the channels between the senses and the heart.

Thereby he states that the channels of the eyes communicate with the veins around the brain (*PA* 656b17; cfr. *HA* 495a11-17). In addition, the philosopher says explicitly that the touch and the taste "are evidently connected to the heart" (*PA* 656a30-31; cfr. *De Sensu*, 439a1-2), but does not explain more precisely why is so [6, p. 80-82].

According to the philosopher, the perceptive-sensory apparatus consists of two different groups of senses and their respective organs. The first group contains the senses of touch and taste, and its organ is the flesh, because it receives the sensation from the outside and transmits it to the heart. The flesh is in fact the primary sense-receptor (*PA* 653b24). The animal is, by definition, that what possesses the senses, and in the first place the first of the senses, the touch. In fact Aristotle observes that "and since perception is present in the simple parts, it is perfectly reasonable for touch to arise in a uniform part, and yet in the least simple of the sense-receptors; for it most of all seems to be a perception of many kinds of things, and the sense-object related to it seems to have many oppositions" (*PA* 647a12-17). Thereby it is necessary that sensations take place in the uniform parts. Moreover the flesh (the sense of touch) and the tongue (the sense of taste), are the instruments of tactile faculties (*DA* 423b26), while the primary sensory, that is the place where occurs the perception, is not the flesh (*PA* 656b35-36), but the inner part of the body – the heart (*De Sensu* 439a2; *PA* 656a29). The second group consists of the senses of smell, hearing and sight (II. 10). The organs of these senses are in the head, because they need pure and cold blood. And also in this case, in a similar way, the channels convey the sensation to the veins and from them the perception reaches the heart [6, p. 82-83; 14, p. 550]. The channels of all sensors are stretched to the heart, and in the animals lacking the heart to its analogue (*GA* 781a21). Therefore the heart becomes the seat of the sensitive soul, so plays a role of the common sensorium (*koinòn asthetérion*). What Alcmaeon had attributed to the brain, Aristotle attributed to the heart.

It should be noted that for the philosopher the heart was not only the place where all the sensory data from the senses converges, but also the origin of all movement (*PA* 665a10-15). As already mentioned, Aristotle was far from knowing that nerves act in order to contract muscles. Nerves will be explicitly identified and distinguished in terms of sensory (*aisthetikà neûra*) and motor nerves (*proairetikà neûra*) a few decades later than Aristotle by two medical theorists: Herophilos of Chalcedon and Erasistratus of Ceos. Aristotle did not distinguish between tendons, ligaments, muscles and nerves. Consequently, the term sinew (*neuron*), used by him and by all physicians and philosophers who had preceded him, denotes the anatomical element that links bones together or muscles and bones together, that is the tendons and ligaments. In fact, in the *PA* Aristotle explains that the heart has plenty of *neûra* and that these elements can generate motion by contracting and relaxing (*PA* 666b14-17). According to the philosopher the heart possesses in its cavity the sinews, and from the heart diverge sinews as the aorta is a similar vein to a sinew. Therefore it is clear that for Aristotle the active part of the muscle contraction was not played by muscle,

but by sinews, that is tendons and fibres derived from blood vessels. These last proceeding to "the periphery" of body become smaller and are transformed into solid elements. By their aggregation they become sinews (*PA* 666b14ff.). Now it is clear that it makes no sense to attribute to Aristotle the enormous absurdity of deriving all the nerves from the heart [6, p. 86-91].

The last step taken by Aristotle to explain voluntary movements consists in the doctrine of *pneûma*, which was not invented by Aristotle, but came from a long ancient tradition. On the one hand, this theory had its origin in the conception of the Homeric *thymós* (the inhaled air gave man life and intelligence), and on the other hand in the doctrine of the *psyché* of Diogenes of Apollonia (the soul as a special entity: *psyché*-aria-*noûs*). In the complex doctrine of *pneûma* that came from Galen, the *pneûma* was considered as the air elaborated at the heart level and transformed, thanks to the vital heat, into *pneûma zotikón* (vital spirit). That was then transmitted through the arteries to all parts of the body, giving them the ability to perform their functions. However, there was a quantity of *pneûma zotikón* destined to go to the brain, and this quantity underwent further elaboration to become *pneûma psychikón* (animal spirit), that is, the spirit by which all operations of the mind are possible. To be precise, Aristotle did not formulate an organic doctrine of *pneûma*, but he referred to it in his different works in order to explain many physiological functions. However there is a substantial difference between the Aristotelian doctrine of *pneûma* and those professed by other physicians and philosophers. For the philosopher, the *pneûma* was aerial, hot substance, of not external but internal origin. Therefore it was the kind of innate or connate substance, called the *sýmphyton pneûma*. It originated inside the body by the effect of the internal heat and it could be turned into steam, or it could be derived from evaporation of the blood. In fact, if the blood evaporation occurred in the heart thanks to the innate heat, the heart is also the seat and origin of breath (*pneûma, PA* 667a28). Although Aristotle, suggested a close relation between the *pneûma* and soul, he did not identify them, but made from the *pneûma* the instrument (*proton órganon*) of the *psyché* (*GA* 762a19-23). Now it seems clear that the philosopher could assign to the *pneûma* the role of the agent of sensations, because sensations had been conceived as a movement, where the stimulus moves the sensory and this movement must be transmitted to the common sensorium (*DA* 416b33, 417a15-21; *De Sensu* 447a15-29). In other words, the stimulus acts by moving the respective sensors, and the latter must transmit the movement (*kínesis*) to the heart, where perception occurs [6, p. 92-97].

It is important to add that the heart is also the seat of the most complex sensations, human emotions (*PA* 666a11-12). This observation is related to Aristotle's criticism of the argument from the *Timaeus* (70C), that the lung serves to calm down too violent palpitations (*pēdēsis*) of the heart. According to the philosopher "it has been claimed – incorrectly – that the lung is connected with the leaping of the heart; I say 'incorrectly' because the occurrence of this leaping happens only, roughly speaking, in mankind, because mankind alone becomes expectant and hopeful for the future. Moreover, in most animals the heart lies at a

great distance from, and in a location higher up than, the lung" (*PA* 669a18-22). Here Aristotle does not mean that beat of the heart (*halsis*; that is the pulsation of the heart; cfr. *De Respiratione*, 479b18ff.) only occurs in the case of humans, but he refers here to the exceptional pulsations caused by emotions [4, p. 657; 1, p. 550].

In the *PA* the *phainomena* revealed by sensitive observation (*aisthēsis*) are considered as an immediate manifestation of reality. Therefore the task of *logos* is to organize and reconstruct them. In the *Parva* or *De Anima* this kind of continuity of the perceptual-cognitive process begins to change, because what is perceived is no longer considered as the simple object (real *ousia*), but as a set of the sensory qualities [4, p. 34-35]. Thereby in the *Parva* the cardiocentric thesis becomes more nuanced, because it is framed in the psycho-physiological investigation linked with the aforementioned doctrine of *pneûma*, resulting in the idea that the function of the sensory faculty consists in cognitive functions that is the perception [10, p. 153-159].

3. The brain

At the time of Aristotle, there were two opposing concepts of the role of the brain. The first one, outlined by Anaximenes, considered the brain as the seat of intelligence. The first main representative of this conception Alcmaeon, has been already mentioned, who was followed by the Pythagoreans, Democritus, Diogenes of Apollonia, the author of *On the Sacred Disease* and Plato. The other conception could be attributed to Heraclitus and his followers, who saw in the innate heat the principle of life and the divine element in man. As mentioned, Empedocles is one of the greatest exponents of this view. This position was later on developed by Aristotle [16]. From what has been said so far results that Aristotle believed that the fundamental factor of all life processes was made up of the innate heat placed in the heart (the hearth of the body). Thus the role of the brain, that is, as the centre of perception and thought, was assigned by Aristotle to the heart [17]. Since Aristotle believed that there was no direct connection between the brain and mental faculties, his research was directed to the moist and fluid nature of the brain (*PA* II.7 652a27-29), and the brain was downgraded to a mere refrigerant organ of the cardiac heat. This approach, that classified the brain as a cold organ, actually persisted in the history of science until the 17th century [16, p. 604-605].

3.1. The process of cooling

It seems that the main reason that led Aristotle to provide the theoretical explanation of the brain comes from his concept of finality present in natural processes (*PA* 645a24-26). According to the philosopher, scientific explanation must investigate the teleology, because "that for the sake of which and the good are present more in the works of nature than in those of art" (*PA* 639b19-21). Aristotle, assured by the principle that nature does nothing in vain, and that the

phainómenon is always true and guaranteed, tries to give an account for the theoretical foundation of the *phainómenon* in his investigations. Sometimes this means that the facts that could not be explained by the scientific knowledge of his time, or the facts coming from only partial observations, were sufficient for him to put in motion the whole 'machine' of his science, to create theoretical explanations of the facts not correctly established [1, p. 531]. A clear example of this can be found in the explanation of the fact that man is the only living being having buttocks (*PA* 689b15-22). It is likely that on the base of his desire to explain differences in animals in a teleological way, sometimes at all costs, Aristotle developed the theory of why nature provided a brain to humans and all blooded animals. The philosopher did not have any intuition of any precise function of the brain, except for its features like coolness and humidity. Consequently, he used these notions, derived from the evidence of his experiences, to assert that nature has furnished all blooded animals with cold and moist brains, with the unique purpose to temper the innate heat [12, p. 315-316].

In fact, in the *PA* Aristotle describes the principle of balance between opposites, the principle also called the principle of compensation (652a30-33). He applies this principle to the brain and to the heart, explaining that the brain belongs to animals for the preservation of their entire nature (652b6-7). This preservation consists in tempering by the brain the heat and the boiling that take place in the heart (652b6-26). This passage contains the essence of the Aristotelian theory of the brain's function, namely the role of cooling the region of the heart. In other words, the brain and the heart are mutually connected in a close manner. The heart could not perform its functions without the cooperation with the brain [16, p. 605; 6, p. 101-105]. It should also be pointed out the reasoning that the philosopher uses to exclude the possibility that the brain could have had any other function than cooling the heart (*PA* 652b23-6). His demonstration could be reconstructed as follows:

Premise$_1$) All animals by nature have at least one organ of perception.
Premise$_2$) If the brain subserved cognition, all animals would have one.
Conclusion) Because the bloodless animals do not, its presence must be explained otherwise.

It should be noted that even if the philosopher attributed to blooded animals a part analogous to the heart, he did not perform an analogical explanation in respect of the encephalon. The unique exception to this, mentioned by Aristotle, was the octopus, considered to have a part analogous to the brain. Also in the *HA* (494b28, 524b4) the cephalopods are deemed to have an analogous part to the brain [12, p. 209-210].

What is the more specific sense of the Aristotle's theory of cooling the body? The heart, in the Aristotelian conception, should be well protected and safeguarded from the excess of the heat via the mechanism of thermoregulation. In other words, the main preoccupation of all ancient medicine and natural philosophy, did not concern the problem of production of the heat (energy metabolism or heat preservation), but rather the issue of efficient heat dissipation in the body. Thus, it was necessary to find the mechanism of the cooling of the

heart. Generally the explanation of Philistion of Locri, Diocles, Hippo, Philolaus dominated, namely, that this function was assigned to the breathing process performed by the lungs and even the skin pores. Also Plato assigned to the air, and in part also to the fluids entering through the trachea, the function of moderating both the heat from the heart and the heat coming from passions (*Timaeus*, 70a-d) [6, p. 112-114]. However, Aristotle offers a somewhat different description of the cooling process. According to him, that process is similar to the formation of rain. The hot steam ascends in the upper parts of the atmosphere and is condensed because of the cooling and then it comes down as rain, bringing refreshment to the earth (*PA* 653a5-10). He proposed the same mechanism to explain sleep (*De somno et vigilia*, 456b17-24, 457b30-458a6). However, the philosopher did not provide any additional explanations on the matter of this process. The Aristotelian theory of the brain function was strongly criticized by Galen, who claimed as Plato (*Timaeus*, 70d), that the process of breathing is enough to cool the heart [6, p. 118-119; 12, p. 210].

It should be mentioned that the Aristotelian explanation of the cooling system mentions not only the brain (II. 7), but also the role of lungs and gills (III. 6). According to Aristotle "it is necessary for cooling from without to be either by water or by air" (*PA* 669a1). In the lungs, cooling is accomplished through the inhaled air. In the bloodless animals this function is accomplished by the innate *pneûma*, but in fish through the presence of gills. The lungs are closely related to the heart, because they receive from it the principle of movement. Moreover according to the philosopher, the lungs are blood free, in the sense that they do not have the blood in themselves. However Aristotle notes that the lungs are porous and rich of numerous veins that contain the blood [1, p. 545-546, 551].

As mentioned above, for the ancient physicians and philosophers the problem of regulation of the heat was the main issue of the functioning of the living beings, namely of their vital homeostasis [13, p. 91]. According to them, the preservation of life and the proper functioning of the whole organism strictly depended on the process of heat dissipation. In the fragments of the *De Juventute et Senectute* (469b21-25; 474b20-24) the philosopher explains the two ways in which the heat is destroyed: the consumption and the extinction. The first consists in the destruction produced by itself while the latter in the destruction produced by contraries elements. Aristotle adds that the first process is caused by the heat excess. In other words, consumption is described as the destruction of the heat by the heat excess and this destruction is called the death. In the *De Respiratione* the philosopher explains that the nature of animals needs the cooling, because of the inflammation of the soul in the heart. This cooling in animals is accomplished through the respiration. Those who have the heart, but not the lungs, such as fishes, cooling is obtained thanks to the water through the gills (478a30-34). Moreover, in these passages, Aristotle mistakenly understood hyperthermia as death by suffocation. Thereby the fresh air entering by inhalation, not only acts as instrument of cooling that regulates heat, but also as instrument of inflammation and therefore sustains the innate heat. In this explanation the air was providing simultaneously two opposite processes: cooling and heating. Aristotle also

assigned to the lungs and to the breathing process, the function of supplying the air to the heart (*HA* 495b8-12). This air, according to some theories (also in the interpretation of Galen), is then used together with the steam coming from the blood and with the air coming through the skin pores, for the formation of the vital *pneûma*. Thus after Aristotle for centuries the main functions of the pulmonary ventilation will remain two: the moderation of the animal heat and the air supply for the formation of the vital *pneûma* [6, p. 114-116].

Aristotle was also aware of the link between the brain and the spinal marrow, but this relation is explained very briefly in relation to the scheme of the cooling process. That is, through the spinal cord, heat is transported to the brain to be cooled. Plato argued in *Timaeus* (75c-d), that the brain has a nature of the marrow. However, Aristotle had no doubt about the opposition of its nature: the marrow is naturally hot, while the brain is among the coldest of the parts within the body (*PA* 652a24-33) [13, p. 89-90].

It could be said, that on the theoretical premises of the Aristotelian description of the cooling mechanism, the latter could be also used to heat the brain, namely that the heart would heat the brain through the blood. However, as already mentioned, Aristotle proposed that the brain cooled the heart. The brain system, in Aristotle's theory, appears as a radiator to dissipate the innate heat, keeping stable the heat in the heart. His position could probably be explained in light of the fact that Aristotle did not know about the circulation of blood. Like Plato (*Timaeus*, 77c-d, 79a), he believed that the blood vessels spread out from the heart to the whole body as gardens aqueducts are constructed from one origin and spring into many channels (*PA* 668a14-35). In this way, the flesh consumes the blood produced in the heart thanks to the action of heat under the raw material coming from the digestion [6, p. 117-118].

To sum up, it should be stressed that the theory of the refrigerating did not have a great follow-up in future research. Among the reasons for its lack of impact could due to one of the most important discoveries in the history of neuroscience, made only a few decades after the death of Aristotle, by Herophilos of Chalcedon and Erasistratus of Ceos: namely, the identification of the sensory and motor nerves as having their origin in the brain. Consequently, the results of their research were adopted in the medical field by Diocles and Praxagoras of Cos and then accepted by the medical sect of *Pneumaticos*. Galen also followed this research, demonstrating that the rational faculty is localized in the brain. Although he did not preclude that emotions could have their origin in the heart. Thanks to these theoretical approaches, the brain became to be considered as the center of perception and sensory integration [6, p. 141-147].

3.2. The brain and perception

The anatomical investigations of Aristotle convinced him that all the processes of perception did not take place in the brain, but, as already explained, in the main organ (*archè*) – the heart. There are three main empirical proofs upon which he based his reasoning in reaching this conclusion.

The first one was derived from the results of a very simple empirical test. Aristotle believed that nothing bloodless is capable of perception, nor is the same blood capable of perception (*PA* 656b19-20). On the base of this reasoning, the philosopher argues that even the brain does not have any perceptive faculties (*PA* 652a35-b1; 656a23-25). His conclusions about the insensibility of the brain substance comes from the proof of mechanical stimulation of the brain (*PA* 652b3-6; *HA* 520b16), in that the brain does not register sensation when is touched. These texts imply that Aristotle performed the vivisection, although it is not specified what kind of animals he used. Aristotle expected that if the animal had felt the stimulus applied to his brain, the animal would have reacted, recording a sensation. However, when he mechanically stimulated the animal brain, he did not observe any animal reaction. It must be said, that the result of his experiment was correct. In fact, the brain and the pia mater have neither touch-pressure receptors nor nociceptors. However, it was incorrect to draw the conclusion from this experiment that the brain could not have any relations with the problem of perception [6, p. 71-73].

The second proof is based on the aforementioned principle of the association of similar, and serves to justify the presence of the main sense organs in the head, but without investigating its functional link with the brain. That principle was based on the evidence of material similarity between properties of senses and material elements constituting them. The channels of communication originated in the eye sensors, called *póroi*, in the *HA* (492a21) are distinguished into three types, spreading from the eye to the brain. One couple of these three channels could be identified as the optic nerves that cross together in the form of chiasma. However, these channels (*póroi*), according to Aristotle, do not serve to transfer the visual information, as happens in the case of the Alcmaeon theory. In the *GA* (744a7-8), examining the eye and the brain development, Aristotle focuses on the fact that the eye is moist and cold, and that from the brain coolness the purest part of the coolness is transported by the channels and is lead through them to the membrane around the brain. In this way he explained the watery quality of the organ of sight [15, p. 221]. Thus, Aristotle interpreted the eye's affinity to the brain not because of the discovery of the optic nerves, but in virtue of the idea of the association of similar properties.

The presence of the sense of hearing in the head is justified by a similar logic. According to the philosopher, this sense is located in the head for two reasons: firstly, that the channel that departs from the ear ends in the back part of the head; secondly, it must be located in proximity to the air in that part of the skull (*PA* 656b13-19). It seems that Aristotle was first to articulate the precise description of the complicated network of canals in the petrous temporal bone and identified the cochlea (*HA* 492a19; *DA* 420a13). To understand better the aforementioned second proof, it must be said that the ancient philosophers and physicians believed that the cavity defined cochlea contained the innate and immobile air, which remains closed inside the ear. Thereby they believed that the main organ of hearing was this air. Aristotle also believed that the back part of the skull was full of air (*HA* 491a30, 494b33-34; *GA* 784a1-3, 784b35, 785a1; *PA*

656b12-13). Now it is clear that if the air was connected with hearing and was the conductive element of sounds, it had to be placed in proximity to the air contained in the back part of the skull (*PA* 656b14-19). The eye had been placed in the head because of the presence of the watery viscera, so hearing had to be placed in the same place, but because of the proximity with the air in the back part of the skull [12, p. 225].

Even for the sense of smell the same reasoning is used, based on the principle of similar, but the explanation remains less clear. According to the philosopher, by nature the aroma is naturally warm and thus is associated with the brain (*De Sensu*, 444a25). The brain as a cold organ could have easily cooled the blood contained by the body, so the smells available to man, prevent that process with their heat, for the protection of human health (*De Sensu*, 444a9-25). In this case, the idea of the association remains the same. However, the strength of the argument seems to be weak and confused [6, p. 73-80].

To sum up, according to Aristotle, the brain does not have anatomical and functional relations with the sensory organs. At this point it is worth emphasizing two things. The first, that already in ancient times there had been established a kind of general rule to counteract the insensitivity of the brain to the strong sensitivity of the meninges, e.g. Erasistratus of Ceos had classified the brain between the *parenchýmata* (the parts of body lacking sensation), while the dura mater was classified as *triplokía* (the structure provided in sensitivity). Consequently, some historians attested that Erasistratus had placed the seat of *hegemonikón* in the dura mater, however Galen argued that Erasistratus identified the origin of the nerves in the brain. The Aristotelian observations of brain insensibility were widely confirmed also by Galen. The latter claimed that the seat of the *hegemonikón* is in the brain, because that is where we find the origin of the nerves, and therefore has to be the location of the main part (*hegemonikón*) of the soul [6, p. 89]. In his proofs he demonstrated that all the nerves are originated in the encephalon and he reflected on the contradiction between the role of the brain in sensory perception and its insensitivity to the application of mechanical stimulus. He explained that the brain is not a sensory organ, but rather the organ that interprets sensations, and called it "the sensorium of the sensors". The second thing worth noting is that about twenty three centuries after Aristotle, the exploration of the cerebral hemispheres of man provided by H. Cushing (1909) and W. Penfield (between 1928 and 1947) showed that the brain actually does 'feels', if it is stimulated adequately; but it cannot 'feel' itself because does not have receptors [6, p. 179-194].

4. Conclusions

The study of Aristotle's discussion of the heart reveals the application of his theoretical concepts of the animal systematic and the composition of living beings. Because the heart is considered by him to be the principle of life, of perception, the motor processes, the animal heat, the nourishment and the growth, it can be said that in some way his conception of organic life circulates around the

theory of this organ. The study of all natural processes linked with the heart shows the theoretical background of his vision of living nature, and helps to see his philosophical concepts grounded in his biological research. In the *PA* the philosopher assigns to the heart the role of the centre of perception and psychical capacities, developing the thought of Empedocles, Philistion of Locri and Philolaus. He attributes to the vascular system the role that would later be assigned to the nervous system. On the one hand Aristotle goes a step further, providing a somatic foundation of the psychic functions and connecting them strongly with organic actions, but on the other hand he is backtracking, because he did not recognize the functional connection between the sense organs and the brain [4, p. 32-33].

From the modern point of view Aristotelian explanations of the brain seem to be absolutely worthless. However, framed in his investigation of the body, they represent a set of important explanations [18]. First of all, the study of the problem of the brain reveals much information about the scientific investigation of the time, about the way of doing observation provided by the ancient physicians. Furthermore, the cooling theory showed a strong thermodynamic approach presented in his study of the living beings. Thus, considering the brain as the cooling organ of the body, of the heart, does not mean only the subordination of the former to the latter, but also shows a complementary, holistic vision of natural processes acting in the organism. In other words, the abovementioned principle of the compensation (or organic equivalents or organic balance) expresses this Aristotelian vision of living nature.

From the discussion about the role of the brain we may derive conclusions about the problem of perception. It is probable that in the historical context of the research conducted by Aristotle, the theory of nerves in the human body had not yet been established and therefore he had to search for other theoretical approaches to explain the connection between the sense organs and the important organs for the functioning of the body. Thus, Aristotle chose the principle of the association of similar (that is the similarity between the organs and the material elements) to interpret the closeness of the senses to the brain. A naïve theory, from the contemporary point of view, however, in that context, is providing physical and physiological explanations of life processes.

Aristotle was that researcher who developed a very complex system of thinking, in many ways near to the modern scientific view. Thanks to his conception of physics based on the four causes and the four elements included in organisms; the conception of the living having in itself the principle of motion; the description of different properties increasing in complexity starting from the plants, via the animals to the man, Aristotle's biology had acquired, for the first time in human history, a systematic approach to the issue of living nature [19]. Thus a great merit of Aristotle as philosopher and biologist is to have founded the science of Biology and the philosophy of Biology. Consequently the Aristotelian inheritance has dominated human thought until the nineteenth century, with a success comparable only to the Euclidean geometry systematization [10, p. 173-174]. The strength and the depth of the Aristotelian study of nature was grounded

in his philosophical ability to wonder in front of reality, since "in all natural things there is something marvellous" (*PA* 645a16-17). The genius of Aristotle the biologist would not exist without Aristotle the philosopher.

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