

The centre thought to control sensory and motor activity in the early history of medicine

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Keywords: induction; brain; heart; sensation; movement

Summary

In Ancient Greek medicine the heart instead of the brain was sometimes thought to be the organ co-ordinating sensory and motor activity. The history of the origin of this erroneous idea is outlined. The relative importance of observations and theory in early medical investigations is discussed, and the anatomical dissections leading to the establishment of the brain as the centre of sensory and motor function are described.

Introduction

In the early days of Greek medicine there was much rational discussion of medical problems, and theories were elaborated which were seldom put to the test of experience. Although for a proper understanding of medical history it is necessary to know the numerous speculative ideas which formed the background to important discoveries it is of interest to trace the actual observations and experiments which led to notable advances being made.

It might be said that on the basis of Sir Karl Popper's ideas on induction this search for significant observations is a wrong approach and that theories however speculative should receive first consideration. Popper rejects the notion that hypotheses are based on observations and asserts that hypotheses come first and then observations are made which serve to corroborate or falsify them¹. He suggests that conjectures or hypotheses depend on intuition and ultimately on an inborn tendency to look for regularities². Sir Harold Himsworth with a first hand knowledge of scientific research has in his book *Scientific Knowledge and Philosophic Thought* challenged some of Popper's ideas. He is concerned that the introduction of intuition and inborn expectations bring an irrational element into scientific procedure and he makes a stimulating defence of inductive methods³. While not everyone will agree with Himsworth's conclusions I found them reassuring when giving priority to the observations which led to the establishment of the brain as the sensory and motor centre of the body. Further comment will be made later on the subject of observation and hypotheses.

The erroneous idea that the heart was concerned with sensations and thought was prevalent among early Greek physicians and my aim is to outline the history of its origin and how it came to be disproved. The theories of Empedocles are especially important as a starting point for the notion that the heart or the blood near the heart is the centre for sensation and thought, but the recognition that these functions belong to the brain resulted from a study of the anatomy of the nervous system.

Early medical references to the brain

One of the earliest references to brain function can be found in the Edwin Smith Papyrus which according to Professor Breasted was written around 1600 BC⁴. In his description of skull fractures the author of the Papyrus recognizes certain features which adversely affect the prognosis, namely, unconsciousness, bleeding from the nose and blood-shot eyes. The absence of throbbing of the brain on palpation by the surgeon is also regarded as a bad sign. Alcmaeon, a Greek living at Croton in southern Italy in the 5th century BC, thought that all the senses are connected in some way with the brain and that they cease to function if the brain is disturbed⁵. This last statement clearly based on observation would seem to point decisively to the brain as the site of sensory function, but this was not generally accepted by Alcmaeon's contemporaries.

Thought related to blood and the heart

Empedocles was a physician and philosopher living at Acragas in Sicily at about the same time as Alcmaeon. He introduced the concept of elements, that is, forms of matter which cannot be broken down into anything simpler. These elements fire, air, water and earth by mixing and separating accounted for the changes in material things revealed by the senses. Everyday objects are composed of these elements in definite proportions and this applies also to the tissues of the body; blood, for example, contains equal portions of all four elements. He thought that pores present in the sense organs receive effluvia given off by the things perceived. The passages of a given sense organ are adapted to receive the effluvia appropriate to it. Ultimately we perceive because an element in the effluvia meets a similar element in the blood where thorough mixing of these entities takes place; and it seems therefore that we think chiefly with the blood⁶. Although Alcmaeon rightly decided that the brain was the seat of consciousness Empedocles in Fragment 94(105), favoured the heart for this function and it was in the blood near the heart that thought occurred⁷.

The physiological ideas of Empedocles, outlined above, are speculative, but their inclusion serves to illustrate the way in which the heart instead of the brain came to be thought of as the central organ of sensation. These alternative views, however, became complicated by the idea that air, which came to the body in respiration, was connected with the thinking process.

Thought related to air and the brain

Anaximenes, a Milesian philosopher living in the sixth century BC, considered air to be the basis of all

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things, for by rarefaction it became fire and by condensation first water and then earth. The air, moreover, was the breath which he equated with the soul. Diogenes of Apollonia who flourished in the 5th century BC appears to have agreed with the views of Anaximenes. He regarded intelligence and thought as due to the finest type of air. Although Diogenes considered air to be the basis of thought, it was air in and around the brain that was especially concerned with this function⁸. There is some evidence from Theophrastus's book 'On the Senses' that Diogenes also allocated some mental function to the region of the heart⁹.

The ideas of Diogenes of Apollonia on the importance of air together with Alcmaeon's conclusion that the brain is the centre for co-ordinating sensations seem to have influenced the writer on 'The Sacred Disease' (epilepsy): this is one of the Hippocratic Treatises most of which were written between 430 and 330 BC. The author considers that the brain is the seat of this disease and he explains the cause in terms of the action of air and humours. Air on entering the body passes to the brain through blood vessels; in the brain it causes consciousness, mental activity in general and movement of the limbs. Consciousness is therefore lost if air is prevented from reaching the brain; epileptics have excess of the humour phlegm and if the routes for its discharge are blocked it enters the blood vessels and shuts off the supply of air¹⁰. The author definitely identifies the brain as the organ which makes it possible for us to see, hear, think and carry out movements of the body, but its actions are dependent on air¹¹.

Plato relates reasoning powers to the brain

Plato (428-347 BC) thought man had an immortal soul endowed with reason and he placed it in the brain, which he regarded as the ruling part of the body, thus following in the tradition of Alcmaeon and Diogenes of Apollonia. He postulated an interaction between the soul of man and the four elements of which the brain was, in his opinion, composed. There were also mortal parts of the human soul, one concerned with emotion which was located in the thorax and another related to appetites which was placed in the abdomen¹². It seems that either blood or blood vessels convey sensation to the brain and thence to the soul¹³. Plato gives a rational account of the body which the gods would be likely to design to house the immortal soul of man and in doing so he takes into account the scanty anatomical and physiological knowledge available. His physiology cannot be regarded as scientific for he does not try to relate his hypotheses to observations on man or animals.

Aristotle makes the heart the sensory and motor centre

Aristotle (384-322 BC), perhaps because he was the son of a physician, had a more practical approach to the world. In his study of animals he actually dissected the parts of their bodies and it is relevant to this essay that the brain was included among them. He described the meninges and distinguished between the cerebrum and the cerebellum¹⁴.

It is important to note that he thought the living differed from the non-living in the possession of a soul. The soul is a Form, pattern or essence, which with

the material of the body constitutes a living thing. The soul has certain powers, one being common to plants and animals, namely, self-nutrition. The human soul has in addition sensation, thinking and movement; these powers with the exception of thinking, the intellectual function, cannot be separated from the body and perish with it at death¹⁵. The separable intellectual power does not, however, possess the characteristics of an individual man and therefore the soul described by Aristotle, in contrast with the Platonic soul, is not endowed with personal immortality¹⁶. This part of the soul definitely has no connection with any organ in the body thus again differing from the Platonic immortal intellectual soul, which was assigned to the brain¹⁷.

Aristotle linked the nutritive and sensitive parts of the soul with the heart and thus continued in the tradition of Empedocles. He also regarded the heart as the source of the innate heat which acted with the power of the soul concerned with nutrition¹⁸. It was therefore the heart, not the brain, which was the central organ of sensation. His reasons for reaching this conclusion were often based on observations which were wrongly interpreted. Nevertheless his approach to the problem was scientific for he was prepared to seek anatomical and physiological evidence for his conjectures, indeed he insisted that in natural science we must first make observations, study the phenomena, and afterwards discuss the causes¹⁹. In his study of the chick embryo he saw the pulsating heart within a few days of the start of incubation of the egg²⁰. He correlated this finding with the inevitability of death when the heart stops beating²¹. The fact that the heart was the first organ to appear active and the last to cease working convinced him that it must be the most important organ in the body and therefore likely to be the seat of the soul. Another reason why he linked sensation with the heart was the obvious association of feelings of pain and pleasure with the action of the heart²². He observed that the brain itself is entirely insensitive and concluded from this that it could not be the cause of any sensations²³.

According to Aristotle if the innate heat, which had its source in the heart, became excessive cooling of the blood was effected by the lungs in respiration²⁴. The brain was also part of the cooling mechanism. He wrongly considered the brain to be devoid of blood and cold; he supposed it exerted a cooling effect presumably on the blood in the meningeal and other intracranial blood vessels²⁵.

How sensations are conveyed from the sense organs to the heart must now be considered, but statements on this question in Aristotle's treatises are somewhat confusing. There are hints that movements of the blood may be responsible²⁶. However, elsewhere it is made clear that blood is devoid of sensation²⁷. Solmsen has discussed the matter in detail and concludes that the evidence points to 'pneuma' as the responsible agent; this pneuma differs from the air mentioned by Diogenes and by the author of *The Sacred Disease* as it is not derived from respiration, but is innate²⁸. There are two passages in the *Generation of Animals* which suggest that the innate pneuma is involved in conveying sensation from the organs of smell and hearing to the heart²⁹. When Aristotle came to explain the origin of movement in animals he is more explicit. The innate pneuma acting from the heart can by expanding and contracting bring about movement³⁰. The views of Aristotle on

the heart as the 'ruling part' and on the importance of pneuma were shared by the physician Diocles of Carystus, a contemporary in Athens, and also by Praxagoras of Cos, the teacher of Herophilus, whose work on the nervous system will now be described. At the time that Herophilus began his anatomical research more physicians favoured the heart than the brain as the central organ of sensation and movement.

Anatomical studies in Alexandria

Herophilus of Chalcedon (fl. c. 300 BC) worked in the medical school in Alexandria. As a result of his human dissections he made important anatomical advances. In his study of the brain he confirmed Aristotle's distinction between the cerebrum and the cerebellum and in addition gave a good account of the ventricles. In contrast with Aristotle he thought that the centre controlling sensory and motor functions was the brain and particularly that part of it in the region of the fourth ventricle³¹. He identified nerves as structures connected to the brain and spinal cord and concerned with sensation and voluntary movement³². Galen in discussing the anatomy of the cranial nerves made it clear that Herophilus had previously carried out elaborate dissections to determine their origin and course³³. There seems to be general agreement among medical historians that Herophilus was the first anatomist to make detailed studies of nerves.

Erasistratus is believed to have been working in Alexandria at about the same time as Herophilus. He did much original work in the physiology of the cardiovascular system, but he also confirmed Herophilus's anatomical findings in the nervous system and amplified them. Thus he made observations on the cerebrum, cerebellum and ventricles, distinguished between motor and sensory nerves and traced the cranial nerves to their origin in the brain. He thought the greater complexity of the cerebral and cerebellar convolutions in man compared with other animals could be correlated with his superior intelligence³⁴.

The dissections of Herophilus and Erasistratus led to the recognition that the nerves were concerned with sensation and motion and their connection with the brain pointed to that organ as the 'ruling part'. Erasistratus incorporated the theory of the pneuma in his physiology. The vital pneuma was derived from air in the lungs and was then located in the left ventricle of the heart and in the arteries; it differed from the innate pneuma of Aristotle in having its origin in the outside air. The arteries contained only vital pneuma. On reaching the brain this vital pneuma was changed to psychic pneuma which then resided in the cerebral ventricles and the nerves. The psychic pneuma in the nerves was responsible for conveying sensations to the brain and movement to the muscles. After the passage of pneuma along motor nerves it caused distension of muscles and as a result they shortened and hence brought about movement of the limbs³⁵.

Galen's work on the nervous system

Although the two Alexandrian physicians had produced such convincing evidence that the brain was the 'ruling part' there were still some philosophers and physicians, especially Aristotelians and Stoics, who were prepared to voice disagreement. Their influence, particularly that of the Stoics, persisted

even in Galen's time (AD 131-201). Galen thought it necessary to provide additional proof that the brain and not the heart was the organ of sensation and movement. He emphasized that anyone undertaking dissection would see that the heart is not the source of nerves for they obviously have their origin in the brain or spinal cord³⁶. In experiments on animals he showed that compression of the brain produced stupor and this was least when the pressure was applied to the lateral ventricles and most profound when it was directed to the brain stem. In this way he related consciousness to cerebral function³⁷. He proved that the capacity for sensation and the capacity for motion is dependent on connections between brain and nerves. Thus he demonstrated that transection of the spinal cord affected sensation and motion in the distribution of all nerves attached to the cord below the level of section. He described the effect on respiration and listed the parts of the upper limbs paralysed or exhibiting sensory loss by transection of the spinal cord at various levels in the cervical and thoracic regions³⁸. In his treatise 'On Anatomical Procedures' Galen gives a detailed account of the course of the vagus and recurrent laryngeal nerves in the neck and thorax³⁹. He observed that animals were deprived of their voices if the recurrent laryngeal nerves were cut. He was able to demonstrate that these nerves are connected to the brain and not to the heart for they leave the vagus nerves before the latter reach the heart. He was thus able to refute the belief of some contemporary physicians that the voice is controlled by the heart⁴⁰.

The theory of the pneuma was still recognized by Galen, but there were points of difference between his pneuma and that of Erasistratus. It was prepared from outside air, undergoing a preliminary change in the lungs and further alteration to vital pneuma in the left ventricle of the heart. Blood charged with vital pneuma was then conveyed to all parts of the body in the arteries. Vital pneuma was transformed into psychic pneuma in the arteries at the base of the brain, and this special pneuma was essential for the proper functioning of the brain and nerves. Belief in the existence of the psychic pneuma was still present in the time of Vesalius in the 16th century. In the 17th century there was a more critical approach to the concepts of 'spirits' such as vital and psychic pneumata, and William Harvey, for example, regarded them as 'a common subterfuge for ignorance'⁴¹.

Observation and hypothesis

Popper thinks there is no such thing as induction; he maintains that observations are made in science in order to corroborate or falsify hypotheses and that falsification not verification is the fundamental principle in scientific method. While it is agreed that falsification is important in science not all would admit that observations have only the place assigned to them by Popper, and this includes Himsforth as pointed out earlier.

Himsforth concedes that once a scientist has formulated a hypothesis it influences what he looks for in subsequent investigations. If we consider the work of Herophilus it seems likely that he had some theory to guide him in his dissections, for example, he would be aware of the possibility of sensory and motor activity being linked either to the heart or to the brain. Although Aristotle gave descriptions of blood vessels he did not distinguish nerves from other

structures, eg tendons. If Herophilus was looking for something linking sense organs to the heart or brain the discovery of structures, ie nerves which in fact made the connection to the brain would be a verification of Alcmaeon's theory or a falsification of that of Aristotle. His work made further advances in the study of the nervous system possible and I think Popper would maintain that this resulted from falsification of Aristotle's ideas. The hypothesis, based on observations first made by Herophilus, that nerves formed a pathway for transmission of sensation from sense organs to brain, was tested by Galen. Severing sensory nerves or their connections to the brain through the spinal cord provided an opportunity for corroboration if sensory loss resulted or falsification if it did not. Popper would regard the positive result achieved by Galen, that is corroboration, as leading to a theory which is again provisional. Falsification is more decisive and this is seen in Galen's experiment on the recurrent laryngeal nerves which refuted the belief that the heart controlled the voice. These investigations of Herophilus and Galen seem to fit in well with the ideas of Popper and yet it is difficult to accept the view that we never make generalizations, form hypotheses, from particular observations.

Himsworth invites us to consider the possibility that Popper may be mistaken when he asserts that observation is always directed by hypothesis. If it were admitted that observation can sometimes be fortuitous then we could imagine the important place of unforeseen observations at the starting points of many of man's trains of thought. There would then be no need for creative intuition or inborn expectations as a source of hypotheses. The question arises whether there is any evidence in support of the occurrence of totally unforeseen observations in science and Himsworth maintains there is; he gives a number of convincing examples which serve to refute the notion that hypothesis must always receive priority⁴². One of Aristotle's ideas noted earlier may here be relevant. He called attention to the relation of feelings of pain and pleasure to the heart's action. The observation that emotion is associated with rapid heart beat and palpitation could well be the starting point for a train of thought leading to the erroneous idea that mental function is centred in the heart. It seems possible that the sensation of palpitation in the chest could be forced upon a man's attention, thus initiating this idea, without a preliminary hypothesis.

The place of inductive methods in science is disputed. The views of Popper are certainly influential, but I think it is fair to say that the problem of induction has not been solved by him to the satisfaction of all philosophers of science⁴³.

References

- 1 Popper K. In: Miller D, ed. *A pocket Popper*. London: Fontana Paperbacks, 1987:102-8,134
- 2 Popper K. *Conjectures and refutations*. London: Routledge & Kegan Paul, 1963:47
- 3 Himsworth H. *Scientific knowledge and philosophic thought*. Baltimore: The Johns Hopkins University Press, 1986
- 4 Breasted JH. *New York Hist Soc Q Bull* 1922;vi:1-31
- 5 Theophrastus. In: Stratton GM, transl. *On the Senses* 26. George Allen & Unwin. 1917:89-90
- 6 Ibid. *On the Senses* 10. 1917:75
- 7 Empedocles. In: Wright MR, ed. *The Extant Fragments*. New Haven: Yale University Press, 1981:130,250
- 8 Theophrastus. *On the senses* 39-40. 1917:101
- 9 Ibid. *On the senses* 45 and 46. 1917:105-7
- 10 Hippocrates. The Sacred Disease Sect. 10. In: Chadwick J, Mann WN, transl. Lloyd GER, ed. *Hippocratic Writings* Harmondsworth, England: Penguin Books, 1978:243-4
- 11 Ibid. The Sacred Disease. Sect. 17 and 19. 1978:248-50
- 12 Plato. *Timaeus* 69-73. In: Lee D, transl. *Timaeus and Critias* Harmondsworth, England: Penguin Books, 1965: 96-101
- 13 Ibid. *Timaeus* 67 and 77. 1965:93-4, 106
- 14 Aristotle. *History of Animals* 494b. 25-32, In: Barnes J, ed. *Complete works of Aristotle*. Princeton: Princeton University Press, 1984:1:788
- 15 Ibid. *On the Soul*. 412b. 10-414a. 29. 1984:1:657-9
- 16 Ibid. *On the Soul* 429a.22-429b.5 & 430a.14-26. 1981:682, 684
- 17 Ibid. *Generation of Animals* 736b.27. 1981:1143
- 18 Ibid. *On Youth, Old Age*. 469a.3-23 & 469b. 3-20. 1981:747-8
- 19 Ibid. *Parts of Animals*. 640a.1-17. 1981:995-6
- 20 Ibid. *History of Animals*. 561a.8-11. 1981:883
- 21 Ibid. *On Youth, Old Age*. 478b.32-479a.2. 1981:760
- 22 Ibid. *Parts of Animals*. 666a.13-14. 1981:1038
- 23 Ibid. *Parts of Animals*. 656a.24-25. 1981:1022
- 24 Ibid. *On Youth, Old Age*. 478a.28-31. 1981:759
- 25 Ibid. *Parts of Animals*. 652a.28-653a. 10. 1981:1015-17
- 26 Ibid. *On Dreams*. 461a.4-30 & 461b.11-14. 1981:733-4
- 27 Ibid. *Parts of Animals*. 666a.17-19. 1981:1038
- 28 Solmsen F. *Greek Philosophy and the Discovery of the Nerves*. Museum Helveticum. 1961:174-8
- 29 Aristotle. *Generation of Animals*. 743b.35-744a.5 & 781a.21-781b.1. 1981:1154, 1208
- 30 Ibid. *Movements of Animals*. 703a.9-28. 1981:1094-5
- 31 Galen. In: May MT, transl. *On the Usefulness of the Parts of the Body*. 8:11. New York: Cornell University Press, 1968:413-15
- 32 Rufus Ephesus. *De anatomia partium hominis* 71-75. In: Von Staden H. *Herophilus*. Cambridge: Cambridge University Press, 1989:200-1
- 33 Galen. In: Duckworth WLH, transl. Lyons MC, Towers B, eds. *On Anatomical Procedures. The Later Books*. Cambridge: Cambridge University Press, 1962:9-10
- 34 Longrigg J. Superlative achievement and comparative neglect: Alexandrian medical science and modern historical research. *Hist Sci* 1981:182
- 35 Wilson LG. Erasistratus Galen and the Pneuma. *Bull Hist Med* 1959;33:310-14
- 36 Galen. *On the Usefulness of the Parts of the Body*. 7:14. 1968:363
- 37 Galen. *On Anatomical Procedures. The Later Books*. 1962:19-20
- 38 Ibid. 1962:22-6
- 39 Ibid. 1962:203-8
- 40 Walsh J. Galen's writings and influences inspiring them. *Ann Med Hist* 1937;ns 9:52
- 41 Harvey W. In: Willis R, transl. *The motion of the heart and blood in animals*. 1628. London: JM Dent, 1906:141
- 42 Himsworth H. *Scientific knowledge and philosophic thought*. Baltimore: The Johns Hopkins University Press, 1986:20-7
- 43 Ayer AJ. *Philosophy in the twentieth century*. London: Counterpoint. Unwin Paperbacks, 1982:131-4

(Accepted 12 March 1991)