Aristotle on the Anatomy of the Brain*

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ARISTOTLE'S theory of brain function has been the subject of several inquiries.[1] Thus it is well known that, contrary to some of his predecessors and contemporaries,[2] he insisted that the brain had nothing to do with sensation. He argued that its main activity was to cool the heat produced by the heart[3] and that the heart and not the brain was the primary organ of sensation.[4] It is the purpose of this paper, however, to examine certain of his statements concerning the anatomy of the brain which, despite the attention paid them by several scholars, remain obscure.

On a number of occasions and in a variety of ways Aristotle asserts that the brain does not fill the cranial cavity and that there is a space in the occipital region. Thus he says: "In the first place then, the brain lies in the front part of the head. And this holds alike with all animals possessed of a brain; and all blooded

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1 Some of the more recent are: T. E. Lones. *Aristotle's researches in natural science.* London, West, Newman and Co., 1912, pp. 173-179. J. I. Beare. *Greek theories of elementary cognition from Alcmaeon to Aristotle.* Oxford, Clarendon Press, 1906, pp. 329-330. A. Souques. *Étapes de la neurologie dans l'antiquité grecque (d'Homère à Galien).* Paris, Masson et Cie., 1936, pp. 105-115. Water Pagel. "Medieval and Renaissance contributions to knowledge of the brain and its function." Pp. 95-114 in *The history and philosophy of knowledge of the brain and its functions,* F. N. L. Poynter, Ed. Oxford, Blackwell, 1958.

2 Alcmaeon (G. S. Kirk and J. E. Raven. *The presocratic philosophers.* Cambridge, University Press, 1960, p. 238, fragment 284), Diogenes of Apollonia (*ibid.,* p. 442, fragment 616), one at least of the Hippocratic writers (E. Littré. *Oeuvres complètes d'Hippocrates.* Tome VI. Paris, J. B. Baillière, 1849, pp. 392-394, "De la maladie sacrée," 17.), Plato (F. M. Cornford. *Plato's cosmology, the Timaeus of Plato,* translated with a running commentary. New York, Liberal Arts Press, 1957, p. 293, 73C-D.), and others agreed that the brain was the central organ of the body.

3 *De partibus animalium* [P.A.], II, 7; 652 a 20. (Vol. V of Oxford translation). Most of Chapter 7 of Book III of this work deals with Aristotle's theory of brain function.

The following convention will be adopted when reference is being made to Aristotle's writings. The abbreviated title of the work will be followed by the book number in Roman, and the chapter number in Arabic numerals. A modified Bekker reference will be added; this will be the page number with the marginal line number from the Oxford translation of the works (*The works of Aristotle.* Translated into English under the editorship of J. A. Smith and W. O. Ross. Oxford, Clarendon Press) which coincides with, or precedes, the beginning of the citation.

4 *P. A.,* II, 10; 656 a 20ff contains Aristotle's argument in favour of the heart rather than the brain being the centre of sensation. Thus, *P. A.,* II, 10; 656 a 25, ". . . it is the region of the heart that constitutes the sensory centre." Also, *De juventute et senectute, etc.* (Vol. III of Oxford translation) III; 469 a 5. "Hence in sanguinous animals the source both of the sensitive and the nutritive soul must be in the heart; . . ." *Ibid.,* 469 a 10, ". . . the supreme organ of the sense-faculties [is] in the heart, for it is here that we must look for the common sensorium belonging to all the sense organs."

animals are possessed thereof, and, by the way, molluscs as well,"[5] and "The back of the head is with all animals empty and hollow, whatever be its size in the different animals,"[6] and further, "The brain in all animals that have one is placed in the front part of the head."[7] There is no doubt that he includes man in these generalizations for, when discussing the human head, he states that "there is no brain in the hinder part of the head;"[8] likewise, "the front part of the head goes bald because the brain is there,"[9] and "men go grey on the temple first, because the back of the head is empty of moisture owing to its containing no brain."[10] When describing the human skull, he states that "the brain lies underneath the sinciput; the occiput is hollow,"[11] the "sinciput" being defined as the front of the skull, and again, "Above the brain is the thinnest and weakest bone of the head, which is termed 'bregma' or 'sinciput.' "[13] Finally he mentions "the cavity in the posterior part of the skull."[14]

At this stage it is necessary to clarify two points. The first is that as far as the normal, human brain is concerned, Aristotle's observations are incorrect. The second concerns terminology, for it is pertinent to enquire what Aristotle means when he uses the word *brain (encephalos).* The obvious interpretation is that the ancient Greeks used the term to indicate simply the structure "within the head."[15] There is no doubt that on many occasions Aristotle used it in this sense, meaning the whole brain, but there is clear evidence that he also employed it to signify the organ, excluding the cerebellum. Thus in two passages[16] he uses the word *parencephalis* to describe the cerebellum, but he uses the same general term, *encephalos,* to designate the remainder of the organ. Only in these passages is it possible to differentiate between the two uses of the word. But on the whole it seems likely that he

[5] *Historia animalium* [*H.A.*] (Vol. IV of the Oxford translation), I, 16; 494 b 25.
[6] *H.A.*, I, 16; 494 b 30.
[7] *P.A.*, I, 10; 656 b 20.
[8] *P.A.*, II, 10; 656 b 10.
[9] *De generatione animalium* [*G.A.*] (Vol. V of the Oxford translation), V, 3; 784 a 1.
[10] *G.A.*, V, 3; 784 a 30.
[11] *H.A.*, I, 6; 491 a 30.
[12] *Ibid.* "The front portion of [the skull] is termed 'bregma' or 'sinciput.' "
[13] *Ibid.*, I, 16; 495 a 5.
[14] *P.A.*, II, 10; 656 b 25.
[15] Liddell, Scott, Jones. *A Greek-English lexicon.* Oxford, Clarendon Press, 1953. s.v. ἐγκέφαλος.
[16] *H.A.*, I, 16; 495 b 30: "Behind this, right at the back, comes what is termed the 'cerebellum,' differing in form from the brain as we may both feel and see." *H.A.*, I, 16; 495 a 10: "From the eye there go three ducts to the brain: the largest and the medium-sized to the cerebellum, the least to the brain itself."

usually applied the word *brain* to the whole brain, as is the usual practice today.[17] On the other hand, in the passages under discussion, if he and his predecessors meant the term to indicate the cerebral hemispheres and underlying structures only, the statement that the main bulk of the brain is anteriorly placed in the cranial cavity would be easier to understand. But this would not account for the occipital space or sac which is an essential part of Aristotle's description.

In an attempt to explain these curious statements, it is necessary, in the first instance, to examine the information concerning the anatomy of the brain which was available to Aristotle. One of his primary objectives was to create a synthesis of Presocratic and Platonic knowledge, and it follows that he would be aware of what had been already contributed to the subject under discussion. As Cherniss[18] has pointed out, if he could demonstrate that his own theories coincided with those of earlier thinkers this was to him additional proof of their validity.

From a study of Presocratic sources, it is clear that a vague idea about the brain similar to the one found in Aristotle's writings was already in existence. Thus Plutarch records the story of how Pericles ordered the examination of the head of a one-horned ram. Anaxogoras, who opened the skull, found that "the brain did not fill the whole cavity, but had contracted itself into an oval form, and pointed directly to that part of the skull whence the horn took its rise."[19] Although elucidation of this anomaly is impossible from the scanty information available, much more substantial statements appear in the Hippocratic Writings. When discussing apoplexy, one writer states that "as for pain at the front of the head, it occurs because the veins are larger and because the brain is greater in the front part of the head than in the back."[20] Furthermore, in the book *On Wounds in the Head* it is stated that most of the brain lies under the front part of the skull and that there is less of it in the occipital region.[21]

17 This conclusion is in keeping with the statement of Galen (see C. Singer, *Galen on anatomical procedures*, London, Oxford University Press, 1956, p. 229) ". . . (ENKEPHALON. I give this name to the compound formed from both the back and front parts). . . . "

18 Harold Cherniss. *Aristotle's criticism of presocratic philosophy*. Baltimore, The Johns Hopkins Press, 1935, p. 349.

19 Plutarch. *Life of Pericles*, 6—Anaxagoras fr. A16 (in) Hermann Diels, *Die Fragmente der Vorsokratiker*. 5. Aufl., Walther Kranz, Ed. Berlin, Weidmann, 1934.

20 Hippocrates. *Diseases II*, 8 (Vol. VII, pp. 16-17, Littré Ed.).

21 *Hippocrates*. London, William Heinemann, 1927 (Loeb Classical Library, Vol. III, pp. 8-13), "On wounds in the head."

"The bone is thinnest and weakest at the bregma, and has the least and thinnest covering of flesh in this part of the head, and there is most underlying brain at this part

It seems certain that Aristotle was aware of this tradition. There are similarities between his own statements and those of the Hippocratic writers for, like them, he notes the weakness of the frontal bone.[22] In fact Poschenrieder[23] has used this passage to demonstrate how closely certain of his statements resemble ones found in the Hippocratic Writings. It is clear from the Hippocratic references, however, that while the authors of the two works mentioned considered the brain to be mainly in the anterior portion of the cranial cavity, unlike Aristotle they did not go further and say, as he did, that the occipital part is empty. There is no clue to indicate how their conclusions were arrived at, but they may have been based initially on simple observation of the human head. The "veins" referred to in the first passage are probably the superficial temporal arteries and they, like the front of the head itself, are more obvious than the corresponding, posteriorly located, structures. Concerning the passage from *On Wounds in the Head*,[24] the author may have been aware that the frontal lobes in man are somewhat larger and blunter than the occipital lobes. However, his conclusion that frontal wounds are more fatal than those in the occipital region is probably due, not to the greater bulk of brain anteriorly, but rather to the fact that depressed fractures with consequent infection were, no doubt, commoner in the frontal region and due also to the higher frequency of such wounds in battle and at other times.[25] It had been well established since the days of Homer, and even earlier, that adequate protection of this region was necessary during combat.[26] Finally, mention must be made of one of the most decisive influences on Aristotle's thought, that of Plato. But as regards the present problem, Plato,

of the head"; "and the greatest part of the brain lies under the bregma"; "also there is less brain in this part [occipital] of the skull."

In the book *Ancient medicine*, XXII (*ibid.*, Vol. I, 1923, pp. 56-59) it is argued that the head (and from the context, the brain within it, although the author does not say so) is likened in shape to a "broad hollow that tapers." Although the "tapering" may suggest the posterior part of the human brain, this deduction would be unwarranted, as the writer is here dealing with theoretical concepts, and in any case the word "tapering" could well be replaced by "contracting."

22 *H.A.*, I, 16; 495 a 5. "Above the brain is the thinnest and weakest bone of the head, which is termed 'bregma' or 'sinciput.'"

23 Franz Poschenrieder. *Die naturwissenschlaftlichen Schriften des Aristoteles in ihrem Verhältnis zu den Büchern den hippokratischen Sammlung*. Bamberg, B. Gartner, 1887, pp. 6-8.

24 *Op. cit.* (note 21).

25 Cf. Plato. *Gorgias*, 469D.

26 H. Fröhlich. "Die Kopfbedeckung der Homerischen Helden." *Virch. Arch. Path. Anat.*, 1876, *68*, 381-398.

in the *Timaeus*,[27] merely emphasizes the importance of the front of the human body as compared with the back, an argument which Aristotle echoes.

Thus a tradition maintaining the presence of more brain in the anterior portion of the cranial cavity was already established before Aristotle's time, and it seems certain that he was aware of it. As far as can be determined from the writings available to us, Aristotle's predecessors did not attempt to explain it, but he endeavored to do so and, as we would expect, his approach is the one he always insisted upon — elucidation of function as a basic step.[28] In the first place, he points out that the brain is mostly in the front of the head because "the direction in which sensation acts is in front"; however, in view of the fact that he did not believe that the brain was a sensory organ, this statement is contradictory. Secondly, "the heart, from which sensation proceeds, is in front of the body," thus indicating again the superiority of the body's anterior surface; it is therefore fitting that the brain, which is second in importance only to the heart, should be situated near to it, rather than to the posterior surface. His final reason was that "the instruments of sensation are the blood-containing parts and the cavity in the posterior part of the skull is destitute of blood vessels."[29]

The first two explanations are neither convincing, nor are they easy for us to understand, although the influence of Plato's teachings is apparent in the second. The third, however, is even more difficult to comprehend, and its elucidation is to be found in Aristotle's account of the form and function of the brain and special senses. Having placed the seat of sensation in the heart rather than in the brain, he then had to account for the fact that the special sense organs in most animals are grouped around the brain and are seemingly in direct connection with it. Why should they be next to an organ which, according to Aristotle's beliefs, has no sensory function? He argues as follows, and in his discussion and explanation of the sense of hearing and sight, Aristotle exhibits three of the outstanding characteristics of his biological method: precise observation, interpretation and explanation of observa-

[27] Cornford, *op. cit.* (note 2), p. 151, 45A.
"And the gods, holding that the front is more honourable and fit to lead than the back, gave us movement for the most part in that direction. So man must needs have the front of the body distinguished and unlike the back; so first they set the face on the globe of the head on that side and fixed in it organs for all the forethought of the soul, and appointed this, our natural front, to be the part having leadership."

[28] *P.A.*, II, 9; 655 b 20. "Our knowledge [of such structures] must come from a study of their functions." Randall (J. H. Randall. *Aristotle*. New York, Columbia University Press, 1960) discusses this aspect of Aristotle's biological research, pp. 225-226.

[29] *P.A.*, II, 10; 656 b 20. These three arguments are listed here.

tional data, and the use of non-empirical, philosophical theories as legitimate explanatory categories.[30] As for the sense of vision, he states, it is evident why it is in the head; the eyes, like the brain, are moist and cold, and since the brain is demonstrably in the head, it follows that the eyes must be similarly located.[31] This argument by analogy may not convince, so a second reason is given; precise discrimination by certain senses is possible only if the blood supply to the organ in question is especially pure, and this is the case with the head.[32] Furthermore the eyes are not connected directly with the brain but rather with the vascular membrane which surrounds it, and thus by way of it, with the heart. Dealing now with hearing, Aristotle, who is here drawing upon established knowledge,[33] explains that it is dependent upon air for its function.[34] This air is enclosed in a chamber,[35] and the so-called empty space at the back of the head is likewise full of air.[36] He then speaks of "a channel which leads back again from each ear and connects it with the hinder part of the head.[37] Although not specifically stated it seems likely from the trend of Aristotle's argument that the connection here is with the occipital empty space.[38]

There are now two explanations possible for the proximity of the ears to the sensationless brain. Firstly, just as it is reasonable for the wet and cold eyes to be near the wet and cold brain, so it follows that the air of the ear is associated with the air-containing occipital space. Furthermore, the ears, like the eyes, are connected

30 Jerry Stannard. "The role of categories in historical explanation." *J. Philos.*, 1959, *56*, 429-447.

31 This argument and its further development are to be found in *P.A.*, II, 10: 656 a 15 ff.

32 *P.A.*, II, 10; 656 b 1: "Moreover, it cannot but necessarily be that the more precise senses will have their precision rendered still greater if ministered to by parts that have the purest blood. For the motion of the heat of blood destroys sensory activity. For these reasons the organs of the precise senses are lodged in the head." (Cf. *P.A.*, IV, 10; 685 b 30 and *De somno et vigilia* (Vol. III of Oxford translation), III, 458 a 10.

33 The pre-Aristotelian theories of the sense of hearing are discussed in detail by Beare (*op. cit.* [note 1], pp. 93-111).

34 *De anima* (Vol. III of Oxford translation), II, 8; 419 b 30: "It is rightly said that an empty space plays the chief part in the production of hearing, for what people mean by 'the vacuum' is the air, which is what causes hearing, when that air is set in movement as one continuous mass."

35 *Ibid.*, II, 8; 420 a 15: "what we hear with is a chamber which contains a bounded mass of air."

36 *P.A.*, II, 10; 656 b 15. ". . . for what is called the [occipital] empty space is full of air."

37 *Ibid.*

38 A. Karsch. (*Aristoteles über die Theile der Thiere. Vier Bücher.* Stuttgart, 1855. No. 25 of a collection entitled "Neueste Sammlung ausgewählter Greichischer und Römischer Classiker verdeutsch" and cited by Sonnenburg [note 46], p. 13), Beare (*op. cit.* [note 1], p. 115), and others have also reached this conclusion.

with the heart by the way of the vascular cerebral membrane and not with the brain itself.[39] Secondly, since the occipital cavity is bloodless,[40] it, like the brain, must be devoid of sensation, and Aristotle can conclude that the associations and connections of the ears with it cannot be for sensory purposes. This is another argument he is able to use to explain the location of the special sense organs in the head, despite the fact that they are, according to his theory, governed by the heart and not by the brain. Although his proposition is not easy to follow, it is nevertheless clear that the air-filled occipital space is an integral and necessary part of it. As Thompson has concluded, part of the reason for Aristotle's insistence on the presence of the occipital space is his belief that hearing is associated with the element air.[41]

It is obviously of importance at this stage to know whether Aristotle had any first-hand knowledge of the inner structure of the adult human body. Owing to the magical beliefs which at this time were associated with death and the dead body, human dissection was not practised and there is no evidence that he dissected a human cadaver.[42] Portal[43] and Lones [44] on the basis of his description of the brain conclude that Aristotle could never have opened a human skull. He did, however, have some empirical knowledge of the animal brain and its coverings, as is clear from several of his statements.[45]

Having considered Aristotle's own justifications and explanations for his peculiar description of the brain, we can now discuss the opinions of others. In the first place, certain authors have

[39] *G.A.*, II, 6; 744 a 1. "These passages [of the ears] end at the small blood vessels about the brain which run thither from the heart."

[40] *P.A.*, II, 10; 656 b 25. "The cavity in the posterior part of the skull is destitute of blood vessels."

[41] *P.A.*, II, 10; 656 b 20, footnote 3.

[42] Ludwig Edelstein. ("Die Geschichte der Sektion in der Antike." *Quell. Stud. Gesch. Naturwiss. Med.*, 1932, *3*, 50-106, and "The development of Greek anatomy." *Bull. Hist. Med.*, 1935, *3*, 235-248) has discussed the general problem of human dissection in antiquity, and Lones (*op. cit.* [note 1], pp. 102-106) has assembled the evidence which indicates that Aristotle had not dissected a human cadaver.

[43] *Baron* A. Portal. *Histoire de l'anatomie et de la chirurgie.* Paris, Fr. Didot le jeune, 1770, Vol. 1, p. 42: "selon lui, le derrière de la tête étoit vuide; se que prouve qu'il n'avoit jamais ouvert de crane."

[44] *Op. cit.* [note 1], p. 103.

[45] He identified an inner vascular membrane (pia mater and pia arachnoid) and an outer stronger one (dura mater) (*H.A.*, I, 16; 494 b 25): he knew that the brain has two halves (*H.A.*, I, 16; 494 b 30) and that the cerebellum lies posteriorly and differs in texture and appearance from the rest of the brain (note 16): the "hollow space" inside the brain (*H.A.*, I, 16; 495 a 5) is no doubt the ventricular system and the fluid he mentions (*P.A.*, II, 6; 744 a 5) was probably the cerebrospinal fluid.

passed the pertinent statements in silence,[46] while others have dismissed them as errors of observation.[47] Lewes, who is always ready to criticise Aristotle, does so on the grounds of these "surprising and unintelligible assertions that there is no brain in the back part of the skull."[48] He claims that this is "the climax of inaccuracy" and that "Aristotle could never have dissected a human subject, perhaps had never seen one laid open; or else they prove that his inspection was careless, his memory treacherous, and his anatomical knowledge extremely superficial."[49] To support these authors there are other examples in Aristotle's writings of inaccurate descriptions of human structures.[50] It is also well known that in the case of some animals (the lion and the crocodile, for example) he was citing the opinions of others and he included their errors; he says, that, unlike other animals, the lion and the wolf have only one cervical vertebra.[51] However, the frequent repetition of the intracranial findings, the varying forms of description, and his own elucidations of them seem to make this possibility unlikely; similar objections could be levelled at those who have contemplated

[46] A. G. Camus. *Histoire des animaux d'Aristote, avec la traduction françoise.* Paris, Desaint, 1783. Vol. I, I/vii, pp. 24-25. Although no comments accompany the text and translation, Vol. II (*Notes sur l'histoire des animaux d'Aristote*) contains lengthy accounts of all the animals recorded in Aristotle's writings, but there is no general reference to the anatomy of the brain.

F. Susemihl. "Kritische Studien zu den zoologische Schriften des Aristoteles." *Rhein. Mus. Philol.*, 1885, *40*, 563-598.

Alfred Volprecht. *Die physiologischen Anschauungen des Aristoteles.* Inaugural—Dissertation, Universität Greifswald. Greifswald, Julius Abel, 1895, p. 16.

Lones, *op. cit.* [note 1], p. 177.

A. L. Peck. *Aristotle. Parts of animals with an English translation.* London, William Heinemann, 1937, pp. 176-179. *Idem. Aristotle. Generation of animals with an English translation.* London, William Heinemann, 1943.

Ingemar Düring. *Aristotle's De partibus animalium. Critical and literary commentaries.* Göteborg, Wettergren and Kerber, 1943. This author, however, like Susemihl (*v. supra*), considers philological problems only.

Louis Bourgey. *Observation et expérience chez Aristote.* Paris, Librarie Philosophique, J. Vrin, 1955, pp. 83-94. Earlier translators and commentators (for example, Fr. Strack: *Aristoteles Naturgeschichte der Thiere,* Frankfort, 1816, cited by Ludwig Sonnenburg, *Zoologisch-kritische Bemerkungen zu Aristoteles Thiergeschichte.* Bonn, Carl Georg, 1857, p. 9.), although recognizing the problem, have no solution to offer.

[47] Jules Geoffroy. *L'anatomie et la physiologie d'Aristote.* Thèse de Paris. Arcis-sur-Aube, Ch. Chapelle, 1878, p. 79.

[48] G. H. Lewes. *Aristotle. A chapter from the history of science, including analyses of Aristotle's scientific writings.* London, Smith, Elder and Co., 1864, p. 166.

[49] *Ibid.*, p. 167.

[50] Cranial sutures (*H.A.*, I, 7; 491 b 1); the uterus (*G.A.*, I, 3; 716 b 30); the kidney (*P.A.*, III, 9; 671 b 5), although in this instance some have argued that Aristotle was describing the lobulated, human, foetal kidney (see Ogle's footnote 4 to *P.A.*, III, 9; 671 b 5); the spleen (*H.A.*, I, 17; 496 b 15); the ribs (*H.A.*, I, 15; 493 b 10); and the heart (*H.A.*, I, 17; 496 a 1; *P.A.*, III, 4; 666 b 20).

[51] *P.A.*, IV, 10; 686 a 20.

textual errors.[52] Aubert and Wimmer[53] have suggested inexpediency in the removal of the brain from the skull, but this likewise is improbable.

Some have adopted a philological approach to the problem. Thus Soury[54] observed that the word "kytos"[55] was also used when a "small hollow" in the centre of the brain was alluded to.[56] Arguing that in the latter statement the ventricular system was intended, he thought that when the same word was used in describing the posteriorly placed intracranial cavity, Aristotle was referring to the fourth ventricle. There is little to support this suggestion, and Soury himself later abandoned the idea. It had been put forward originally by Sprengel[57] whose reasoning, however, does not seem to have been philological. Sonnenburg[58] defends Aristotle by maintaining that the word *inion,* usually employed to describe the occipital portion of the skull,[59] can be translated as *the neck.* Even if this were so, the difficulties of interpretation are by no means surmounted, for, as Lewes observes, "the neck is not more empty than the skull.[60]

Since these explanations are all unsatisfactory, in a search for a more appropriate elucidation it can be argued that if Aristotle did not dissect an adult human brain, his information may have been derived either from the examination of a human foetus, from the observation of pathological conditions in man, or from the dissection of living forms other than man.

Concerning the first possibility, Lones[61] has discussed Aristotle's conceivable experience with human embryological material,

52 Barthélemy Saint-Hilaire. *Histoire des animaux d'Aristote.* Paris, Librarie Hachette et Cie, 1883, p. 44, footnote 3. A. von Frantzius (*Aristoteles vier Bücher über die Theile der Thiere.* Leipzig, Wilhelm Engelmann, 1853, note 53 on p. 280) justifiably denies this possibility.

53 H. Aubert and Fr. Wimmer. *Aristoteles Thierkunde kritisch-berichtigter Text, etc.* Leipzig, Wilhelm Engelmann, 1868, Vol. I, p. 215, footnote 39.

54 Jules Soury. *Ie système nerveux central. Structure et fonctions. Histoire critique des théories et des doctrines.* Paris, Georges Carré et C. Naud, 1899, p. 107

55 *P.A.,* II, 10; 656 b 25. In the Oxford translation this is given as *cavity*— ". . . and the cavity in the posterior part of the skull is destitute of blood vessels"—whereas Peck (*op. cit.* [note 1], p. 179) prefers "sac"—". . . whereas the sac at the back of the head contains no blood vessels at all."

56 *H.A.,* I, 16; 495 a 5.

57 Kurt Sprengel. *Histoire de la médecine depuis son origine jusqu'au dix-neuvième siècle,* A. J. L. Jourdan, Tr. Paris, Deterville and Th. Desoer, 1815, Vol. I, p. 389: "Il existe dans la tête un espace vide; c'est vraisemblablement des ventricules du cerveau dont il est question ici."

58 Sonnenburg, *op. cit.* (note 46), pp. 11-12.

59 *H.A.,* I, 7; 491 a 30.

60 *Op. cit.* (note 48), p. 167.

61 *Op. cit.* (note 1), p. 104.

and Menetrier[62] has gone further by suggesting that the Hippocratic writers, as well as Aristotle and other early Greek scientists, obtained their knowledge of human structure from the dissection of still-born foetuses and new-born infants. It is known that Aristotle examined a male human foetus of about 40 days,[63] and in this connection he makes a curious statement: the human and animal foetal brain is large and fluid, he says, but later, due to evaporation and coction, it shrinks and becomes more solid.[64] However, there is no evidence that any space exists in the occipital region of the normal embryo either at term or at any time during its development.[65]

Pathological conditions of the brain and skull of the human foetus or adult must be considered next. Such lesions as porencephalic cysts of the occipital lobes, a congenital occipital encephalocele, or cerebral cysts of vascular, neoplastic, or parasitic etiology might possibly produce a state of affairs approximating Aristotle's various descriptions. No known lesion, however, could produce the empty or air-filled space which his accounts demand, except perhaps the presence of gas-forming organisms in a decomposing brain examined in a corpse lying prone. He may have encountered cranial injuries, since it seems likely that he saw the results of battle trauma,[66] although only once is a head injury mentioned;[67] and perhaps other pathological states were called to his attention.[68] It is natural to consider here the possible influence of the Hippocratic work *On Wounds in the Head*. Although it has already been argued that a connection probably exists, a satisfactory answer concerning clinical details is not forthcoming. In any case it is difficult to understand how any of the known traumatic cranial or

62 P. Menetrier. "Comment Aristote et les anciens médecins Hippocratiques ont-ils pu prendre connaissance de l'anatomie humaine?" *Bull. Soc. franç. Hist. Méd. (Paris)*, 1930, *24*, 254-262. Theodor Gomperz *(Greek thinkers. A history of ancient philosophy*, G. G. Berry, Tr. New York, Charles Scribner's Sons, 1912, Vol. IV, p. 140) also supports this belief.

63 *H.A.*, VII, 3; 583 b 10. Ogle, commenting upon *P.A.*, III, 9; 671 b 5 (footnote 4), uses Aristotle's description of the human kidney as additional evidence for this.

64 *G.A.*, II, 6; 744 a 15. Aristotle is discussing the embryology of the eyes and the brain. Concerning the latter, he says: ". . . at first it is liquid and large, but in course of evaporation and concoction it becomes more solid and falls in."

65 W. T. Peyton. "A study of developmental cranio-cerebral topography as determined by the orthoscopic method." *J. nerv. ment. Dis.*, 1933, *78*, 232-249, 381-399.

66 In *P.A.* III, 3; 664 b 15. He mentions penetrating wounds of the stomach and speaks of battle wounds in *P.A.*, III, 10; 673 a 10, but on this occasion it is clear that he is citing the experiences of others.

67 He describes a blow in the temporal region which produced unilateral amblyopia *(De sensu* [Vol. III of Oxford translation], II; 438 b 10); in this regard, it is now known that the site of election for trauma which results in an optic nerve lesion is, as in this case, the outer and upper portion of the orbital rim.

68 *P.A.*, III, 5; 667 b 1. He mentions here the various disease processes discovered in sacrificial victims, but these are restricted to the abdominal and thoracic viscera.

cerebral lesions could have suggested an empty occipital region as a constant feature of the human and animal skull.

On the basis of the foregoing it seems unlikely that Aristotle had any empirical anatomical evidence for his assertions concerning the human brain, and the final possibility must now be discussed. He admits that when he lacked data on human anatomy, especially that of internal structures, he generalized from his knowledge of lower animals,[69] and he justifies this practice on the grounds that there is a correspondence between human structure and its homologue in vertebrates of a lower order.[70] Even so, it is still difficult for us to understand how he was able to make such transferences,[71] especially as he states that both external and internal parts vary in different animals.[72] Biological generalizations, although forming one of the foundations of his researches in physiology and anatomy, and although responsible for his most remarkable success, led him astray occasionally. He continually sought equivalents of the form and function of tissues and organs of one class of animals to all others.[73] Moreover, for him there was no distinct line between cold—and warm-blooded animals, which to us is fundamental. It can therefore be suggested that some of his statements about the brain in general, including that of man, may have been derived from his experience with lower animals, and perhaps with the cold-blooded species in particular.

Part of Aristotle's general theory of brain function depends upon the idea that the brain is bloodless and he repeats this statement on several occasions.[74] But, as Lewes[75] indicates, this may have arisen from the inspection of a fish brain, or a brain that had been cooked; he does in fact mention the changes observed when a brain, presumably of an animal, is boiled.[76] Furthermore, as

[69] *H.A.*, I, 16; 494 b 20. "For the fact is that the inner parts of man are to a very great extent unknown, and the consequence is that we must have recourse to an examination of the inner parts of other animals whose nature in any way resembles that of man." An example of inference in man is given in P.A., IV, 2; 677 a 5: "For, almost invariably, those who suffer from these forms of disease [acute] are persons who have no gall-bladder at all, as would be quite evident were they to be dissected." Cf. *Politics*, VII, 15; 1336 a 5.

[70] Cf. *P.A.*, I, 4; 644 b 5 sq. For a discussion of this and related passages, see F. S. Bodenheimer. *The history of biology*. London, Dawson, 1958, pp. 15-16.

[71] Examples which are easier for us to understand are as follows: he identified the dog's stomach (*H.A.*, I, 16; 495 b 20), as well as the pig's lower gut (*ibid.*) and spleen (*H.A.*, I, 17; 496 b 20) with those of man.

[72] *P.A.*, III, 4; 665 b 1.

[73] See Bodenheimer (note 70), pp. 15-17.

[74] For example: "The brain of all animals is bloodless, devoid of veins, and naturally cold to the touch." (*H.A.*, I, 16; 495 a 5); "the brain itself in all animals is destitute of blood, and no vein, great or small, holds its course therein." (*H.A.*, III, 3; 514 a 15); "for in fact it [the brain] has no blood at all in its proper substance." (*P.A.*, II, 7; 652 a 35).

[75] *Op. cit.* (note 48), p. 166.

[76] *P.A.*, II, 7; 653 a 20.

already noted, according to Aristotle the brain of the developing animal, instead of growing, shrinks.[77] Now there are at least two passages in his writings which indicate that he examined the brain of a fish,[78] and it is well known that whereas the brain in the fish embryo fills the cranial cavity completely, owing to the disproportion between its growth and that of the skull, in the adult it occupies only a portion of the potential space.[79]

Further attention is drawn to the possible role of cold-blooded animals by Ogle when he comments upon the passage, "for there is no brain in the hinder part of the head."[80] Moreover, Thompson[81] has remarked upon Aristotle's considerable knowledge of marine biology, and it is clear from his writings that he was as well acquainted with cold-blooded animals as he was with warm-blooded species. In fact, it is likely that he had a wider knowledge of their internal structure, for of the 49 animals he is thought to have dissected,[82] 29 are poikilothermal; of these there are four kinds of reptiles and 22 amphibians, fish, and lower orders of aquatic life. Ogle[83] points out that in certain reptiles, as well as in fish already mentioned, the brain does not fill the cranial cavity completely.

One reptile with which Aristotle was familiar is the turtle. Certain varieties of this animal have been amphibious marsh dwellers since the late Triassic,[84] and a habitat such as he is known to have encountered on the shores and in the shallow lagoons of the Aegean and where he carried out most of his biological research[85] would be ideal for them. Sundevall[86] has identified the varieties of

77 *Op. cit.* (note 64).

78 *H.A.*, IV, 8; 533 b 1 and *H.A.*, I, 16; 495 a 10.

79 C. L. Herrick and C. J. Herrick: "Contributions to the morphology of the brain of bony fish." "Siluridae" by C. J. Herrick. *J. comp. Neurol.*, 1892, *1*, 211-245 (see p. 212): "the brain practically ceases to grow when the fish attains a modest size—the cranial cavity, however, enlarges more nearly in proportion to the size of the head. In larger specimens it is more than twice the size of the brain, which lies in the ventral and caudal portion." Ogle (*P.A.*, II, 10; 656 b 10, footnote 1) also notes the phenomenon. Geoffroy (*op. cit.* [note 47], p. 79, footnote 1), when commenting on Aristotle's description of the brain, mentions the fish brain.

80 *Op. cit.* (note 79).

81 D'Arcy W. Thompson. "On Aristotle as a biologist": in *Toward modern science*. R. M. Palter, Ed. New York, Noonday Press, 1961. Vol. I, pp. 66-67. H. D. P. Lee ("Place names and the dates of Aristotle's biological works." *Class. Quart.*, 1948, *42*, 61-67) has also examined this aspect of Aristotle's biological studies.

82 Lones, *op. cit.* (note 1), p. 106.

83 *Op. cit.* (note 79).

84 A. S. Romer. *Osteology of the reptiles*. Chicago, The University of Chicago Press, 1956, pp. 496-497.

85 Thompson and Lee, *op. cit.* (note 81).

86 C. J. Sundevall. *Die Thierarten des Aristoteles von den Klassen der Säugethiere, Vögel, Reptilien und Insekten.* (Übersetzung aus dem Schwedischen) Stockholm, Samson and Wallin, 1863, pp. 174-175. See also Camus (note 46, Vol. II, pp. 309-310 and pp. 811-813) who also discusses the species of turtle Aristotle is likely to have examined.

turtle which Aristotle probably encountered: the marine,[87] the fresh-water,[88] and the terrestrial species.[89] He may also have been familiar with the larger species from the Arcadian forests reported by Pausanias,[90] or from the Indian Ocean and Red Sea described by several authors of Graeco-Roman times.[91] In this respect, Agassiz[92] notes the remarkable similarity between the general structure of the brains of various species of turtles, although minor variations in specimens of different families do occur.

Aristotle mentions the turtle on several occasions[93] and there is no doubt that he dissected this reptile. Moreover, he must have vivisected one in order to examine the heart *in vivo*.[94] He does not, however, mention the skull or brain, although he does describe the kidneys. Here an interesting observation can be made. When dealing elsewhere with the human kidney he says that it is lobulated: "as it were made up of numerous small kidneys, and not presenting one unbroken surface."[95] This is the passage which suggested to Ogle[96] that Aristotle had examined a human fetal kidney which has a lobulated structure, whereas the adult organ does not. However, when describing the turtle kidney, which he correctly records as lobulated,[97] Aristotle makes a statement very similar to the one just cited: "it looks like one single organ composed of a number of small ones."[98] Although the kidney is also lobulated in the ox, elephant, and bear, as far as is known he dissected only the first two of these and records his findings concerning the kidney, and these correctly, only in the ox.[99] It is conceiva-

87 For example *P.A.*, II, 8; 654 a 5. ". . . namely, the Tortoises, including the Chelone and the several kinds of Emys." *Chelone* was used in Greece generally for land turtles, and also as a generic term for any turtle.

88 *H.A.*, V, 33; 558 a 5. "The hemys, or freshwater tortoise." *P.A.*, III, 9; 671 a 30: "The Emys has neither bladder nor kidneys." This is probably *Emys orbicularis*, the European pond tortoise discussed by Camus (*op. cit.* [note 46], Vol. II, pp. 309-310) and by Lones (*op. cit.* [note 1], p. 238). See also *P.A.*, III, 8; 654 a 5.

89 For example, *Testudo graeca* of southeast Europe, or *T. marginata*.

90 *Description of Greece.* Book VIII, xxiii, 54: ". . . and tortoises [chelonas] of vast size. One could of the last make harps not inferior to those made from the Indian tortoise [chelones]."

91 Pliny. *Natural history*, IX, 12, 35 sq. *Diodorus of Sicily*, III, 21. Strabo. *Geography*, XVI, iv, 14. Lenz (H. O. Lenz. *Zoologie der alten Griechen und Römer*. Gotha, Becker, 1856, pp. 413-418) gives other references to the turtle in the writings of classical antiquity.

92 Louis Agassiz. *Contributions to the natural history of the United States of America*. First Monograph, Vol. I. Boston, Little, Brown and Co., 1857. Part II, "North American Testudinata," p. 362. "All turtles agree among themselves very remarkably in the structure of the brain."

93 Hermann Bonitz. Reprint edition Graz: Akademische Verlag, 1955, p. 244a 37-60 s.v. ἐμύς and pp. 849b 19-850a 10 s.v. χελώνη.

94 *De juventute et senectute*, II, 468 b 15.

95 *P.A.*, III, 9; 671 b 5.

96 *Ibid.*, footnote 4.

97 C. K. Reichert. *The anatomy of the chordates*. New York, McGraw-Hill Book Co., Inc., 1958, p. 254.

98 *H.A.*, II, 17; 506 b 25.

99 *Ibid.*: "In the turtle the kidney resembles the same organ in the ox."

ble, therefore, that he was transferring his anatomical knowledge of the turtle to man and, if he did this with the kidney, it is not unreasonable to suggest that he could have done the same with the brain, although a similar use of other reptiles or even other animals is a possibility which cannot be excluded.

The turtle is the reptile selected by Ogle[100] for special mention when he comments upon Aristotle's claim that there is no brain in the posterior portion ofthe head. As has already been noted, the brain of fish and of some reptiles does not fill the cranial cavity completely. This is also true of the turtle. Lamarck[101] thought this feature to be of such fundamental importance that he employed it as one of the criteria in his proposed classification of the animal kingdom. Thus fish and reptiles are considered to have, amongst other distinguishing features, nerves which end in a brain the volume of which does not equal that of the cranium, whereas in birds and mammals it does. Desmoulins[102] as long ago as 1825 pointed this out in fish and turtles and found that the brain of the latter occupies only two-thirds of the potential space; a more recent observer,[103] however, estimated the brain volume as not more than one-third of the cranial capacity. An interesting observation in this respect was made by Agassiz in 1857 when, having stated that "the form of the brain [of the turtle] has no immediate bearing upon the form of the skull," he remarks upon the obvious contradiction this makes with the doctrine of phrenology.[104] Although Aristotle makes no mention of the turtle skull or brain, he seems to have been aware of the disparity between brain and skull volumes, and he may have observed the phenomenon in the turtle as well as in the fish.[105]

But before looking more closely at the intracranial possibilities for his general statements about the form of the brain, we must examine an aspect of the reptilian skull itself. Regarding a passage

[100] *Op. cit.* (note 79).

[101] J. B. A. P. Monet de Lamarck. *Philosophie zoologique.* Paris, Librairie F. Savy, 1873, Vol. I, p. 276.

[102] A. Desmoulins. *Anatomie des systèmes nerveux des animaux à vertèbres, appliquée à la physiologie et à la zoologie.* Paris, Méquignon-Marvis, 1825, Vol. I, p. 109. "Mais dans la plupart des reptiles et dans tous les poissons, le volume du cerveau est quelquefois moindre que le tiers et même que la moitié de la capacité du crâne." In the section on the cranium (J. Malyn, pp. 724-726 of *The cyclopaedia of anatomy and physiology,* R. B. Todd, Ed., London, Longman, *et al.,* 1835-1836, Vol. 1, A-Dea, p. 724) Todd adds an editorial comment that "according to Desmoulins the area of the vertical section of the brain in the European tortoise is nearly one-third less than the area of the cranial cavity; and in fishes, whether osseous or cartilaginous, the disproportion is constantly still greater."

[103] O. D. Humphrey. "On the brain of the snapping turtle (Chelydra Serpentina)." *J. comp. Neurol.,* 1894, *4,* 73-116 (see p. 75).

[104] *Op. cit.* (note 92).

[105] *Op. cit.* (note 64).

from the *Historia animalium,*[106] it can be argued that when Aristotle says that "the occiput is hollow," he is in fact referring to the cranial bone itself, rather than to that portion of the intracranial cavity which underlies it. The term *inion,* like our word *occiput,* may have referred to the occipital bone as well as to the posterior part of the head, inside or outside. If this were so, one might suppose that Aristotle is indicating the skull vacuities of certain animals, spaces which are especially characteristic of some reptiles. A vacuity is a space which is produced when two or more bones draw apart during development, but they are found only in the temporal region and they do not occur in the turtle skull.[107] Some species of turtle and some other reptiles have a deficiency of the occipital bones or a defect in the posterior temporal region, but these do not represent vacuities[108] and Aristotle could not have encountered the species in which they occur most commonly, the North American snapping turtle (Chelydridae).[109]

As Aristotle specifically mentions a *cavity* at the back of the head[110] and also places it in relationship with the air-filled ear,[111] it is reasonable that the mastoid air cells should be suggested as a possible solution to the present problem. Thus Aubert and Wimmer[112] believed that Aristotle must have been referring to the mastoid air cells or frontal sinuses, which in some animals, the ox for example, have considerable posterior extensions. The role of the mastoid cells was also favoured by Thompson,[118] who points out how they may be readily demonstrated by simply percussing the mastoid process; it is, however, difficult to agree with this author if one taps different areas of the skull. On the whole these claims are far from satisfactory.

If Aristotle had opened the skull of a turtle, it is interesting to

[106] *H.A.,* I, 7; 491 a 30. "The brain lies underneath the sinciput; the occiput is hollow." (". . .; τὸ δ'ἰνίον κενόν") Cf. note 59.

[107] J. T. Saunders and S. M. Manton. *A manual of practical vertebrate morphology.* London, Oxford University Press, 1949, pp. 130-132.

[108] Romer, *op. cit.* (note 84), p. 99.

[109] A. d'A. Bellairs. *Reptiles. Life, history, evolution, and structure.* New York, Harper and Brothers, 1957, p. 66.

[110] *Op. cit.* (note 55).

[111] *Op. cit.* (note 36).

[112] Aubert and Wimmer (*op. cit.* [note 53], p. 215, footnote 3) say that Schneider was the first to make this suggestion, but this could not be verified in J. G. Schneider. *Aristotelis de animalibus historiae.* Liber X. Tomus III. Lipsiae, in Bibliopolio Hahniano, 1811. Franzius (*op. cit.,* note 52) should also be mentioned in this regard. He comments on *P.A.,* II, 10; 656 b 10 (see text quotation to which note 8 refers) and he may be referring to Schneider when he points out that the frontal sinus is a most unlikely possibility. Apart from also denying that the passage (*P.A.,* II, 10; 656 b 10) could have been distorted by textual corruption, or that it is a faulty interpretation, he has no explanation to offer for the occipital space.

[118] *H.A.,* I, 7; 491 a 30, footnote 5.

consider what he may have discovered. The brain of the turtle is not too small to be examined macroscopically[114] and in this regard it is interesting to note that Aristotle was able to examine carefully and describe accurately the eye of the mole[115] despite the fact that it is only 1/25th of an inch in diameter.

When the skull of a turtle is opened from behind,[116] the meningeal membranes hang loosely in the cavity and when these are divided it is evident that the brain does not fill the cranial cavity. As the brain tapers caudally, and as the frontal portion is disproportionately large, one gains the impression that there is in fact more of the organ in the anterior part of the cavity. Furthermore, the empty space, although present anteriorly, seems to be greater posteriorly. Lones[117] makes the interesting observation that Aristotle probably dissected animals placed in a vertical, or near-vertical, position. If this were so, when he opened the skull of a specimen and breached the meninges, the cerebrospinal fluid would drain away more effectively than if the specimen were in a horizontal position. In cases where the skull was not completely full of brain, a cavity between the calvarium and the organ would thus be produced, and his statement that "the back of the head is empty of moisture owing to its containing no brain"[118] should be noted in this regard.

The roof of the capacious fourth ventricle is covered by the telachoroidea. In addition, Munson[119] has described what he calls a brain bladder in this area, a structure which is characteristic of the turtle brain; it is also present in man but only at an early stage of development. It is a closed sac lying in the subarachnoid space but distinct from it. It projects through the pia at the caudal end of the fourth ventricle on the dorsal surface of the brain and fills the posterior part of the cranial cavity, for it has the dimensions of "a good-sized soap bubble."[120] In a traverse section of the skull it can be seen reaching out to the inner table of the skull. It is not always possible to demonstrate this structure but it is known that in elasmobranch fish tilting the body will induce gravitation of fluid to the caudal extremity of the fourth ventricle

114 J. P. Munson. "Chelonian brain-membrane, brain-bladder, metapore and metaplexus." *J. comp. Neurol.*, 1913, 7, 169-180 (p. 169).

115 *H.A.*, IV, 8; 533 a 1 and *H.A.*, I, 9; 491 b 25.

116 The North American *Pseudemys scripta elegans*, or red-eared turtle, was dissected.

117 *Op. cit.* (note 1), p. 103. Cf. also Thompson *op. cit.* (note 81), p. 71.

118 *G.A.*, V, 4; 784 b 30.

119 Munson, *op. cit.* (note 114).

120 *Ibid.*, pp. 173-175.

with the consequent protrusion of its membranous roof.[121] This also occurs in the turtle, for Humphrey describes the roof membrane extending caudally as a distinct pocket and observes that it "takes whatever form pressure and gravitation may dictate."[122] Thus tilting the specimen, as may have been Aristotle's custom, may have induced bulging of the roof of the fourth ventricle with the possible demonstration of the bladder. In one of Aristotle's passages already cited he speaks of a *kenos,* or *cavity,* or *sac* at the back of the head.[123] The structures here described may possibly account for these assertions. Moreover, if Aristotle vivisected the turtle's brain as well as its heart,[124] these parts might have been more striking than is the case in the usual preserved specimen of today; they have, of course, never been described in the unanesthetized, living animal by modern anatomists or zoologists.

Finally, there is another interesting anatomical structure which should be mentioned. During the early development of the human internal ear the endolymphatic duct is prominent, although later it is of insignificant size. The duct is a tubular extension of the sacculus and passes through the vestibular aqueduct to end intradurally as the endolymphatic sac.[125] The duct and its sac are more highly developed in certain lower animals, especially in fish and certain reptiles. In the turtle and several lizards, the sacs are of considerable size.[126] They lie in the intracranial cavity dorsal to the caudal end of the brain and reach up to the longitudinal dural sinus.[127] Their prominence is inferred from a general statement of Romer: "the brain case in reptiles is not, in general, closely appressed to the brain in all areas, and other structures (such as endolymphatic and perilymphatic sacs) may be present in the endocranial cavity."[128] They do not connect with the subarachnoid space and although they are associated with the vestibular apparatus, their function is obscure. According to Dempster, "a tube leads from the main sacs cephalo-ventrad along

121 J. A. Blake. "The roof and lateral recesses of the fourth ventricle, considered morphologically and embryologically." *J. comp. Neurol.,* 1900, *10,* 79-108 (see p. 96).

122 Humphrey, *op. cit.* (note 103).

123 *Op. cit.* (note 55).

124 *Op. cit.* (note 94).

125 T. H. Bast and B. J. Anson. *The temporal bone and the ear.* Springfield, Ill., Charles C Thomas [1949], pp. 43-62.

126 Romer, *op. cit.* (note 84), p. 36. See also Franz Keibel. "Der ductus endolymphaticus (Recessus labyrinthi) bei Schildkröten." *Anat. Anz.,* 1915-16, *48,* 466-474, where the ducts are shown by serial section in the embryo.

127 W. T. Dempster. "The morphology of the amphibian endolymphatic organ." *J. Morphol.,* 1930, *50,* 71-120. See also Guiseppe Sterzi: "Il sacco endolinfatico. Ricerche anatomiche ed embriologiche." *Gegenbaurs morph. Jb.,* 1909, *39,* 446-496 (see pp. 476-479).

128 *Op. cit.* (note 84), p. 21.

the lateroventral margin of the cerebellum to the ear cavity,"[129] but both this and the thin-walled sacs may be difficult to identify.

As we have seen earlier, when Aristotle is discussing the faculty of hearing, he says "there is a channel which leads back again from each ear and connects it with the hinder part of the head."[130] As a step in the formulation of his theory of brain function the channel is of considerable importance. The word *channel (poros)* creates the usual difficulties, and Ogle[131] gives a brief summary of a much discussed problem. Whereas some believe that blood vessels are referred to in this passage, Ogle suggests the internal auditory meatus which in man carries the auditory and facial nerves. From the above consideration, however, there seems to be also a third possibility.

Another reptile with which Aristotle was familiar, perhaps even more so than with the turtle, is the chameleon.[132] He states that "the brain is situated a little above the eyes, but connected with them."[133] Although this may suggest an anteriorly placed brain, the shape of the animal's skull and the large size of its eyes must be taken into account.[134] The relative volume of brain and skull, and well-developed endolymphatic sacs, make comparisons with the turtle possible. Aristotle seems to have vivisected this animal, as well as the turtle.[135]

Numerous tentative explanations for Aristotle's description of the skull and brain have been presented but it should be emphasized that possibly none of them is appropriate. Of all the ancient philosophers Aristotle is perhaps the most difficult to comprehend adequately, and in a problem such as the present one it is not easy to separate the various strands that enter into the composition of this argument. But while it must not be forgotten that he was the first biologist of rank, equally so, it must not be overlooked that he was also a philosopher. If it can be substantiated that he viewed

129 *Op. cit.* (note 127), p. 107.

130 *P.A.*, II, 10; 656 b 15.

131 *P.A.*, II, 10; 656 b 15, footnote 2.

132 Thompson (*op. cit.* [note 81], p. 67) notes that the chameleon is common in the Aegean Islands where Aristotle did his work but does not occur on the Greek mainland.

133 *H.A.*, II, 12; 503 b 15.

134 Julia Gisi: "Das Gehirn von Hatteria punctata." *Zoolog. Jb. Abt. Anat. Ontog.* (Jena), 1908, *25*, 71-236 (see pp. 216-217). The author compares the New Zealand tuatara with reptiles, including *Chamaeleo vulgaris*. The literature on the chameleon brain is very meager, and such articles as P. Ramón. "Estructura del encéfalo del camaleon." *Rev. trimest. Micrográf. (Madrid)*, 1896, *1*, 46-82 deal only with histological appearances. Mention should be made of one earlier work: Claude Perrault. *Description anatomique d'un chameleon, d'un castor, d'un dromadaire, d'un ours, et d'un gazelle.* Paris, Frederic Leonard, 1669. A chameleon is pictured on Plate I; the upper portion shows the skeletal system in which the cranial cavity is clearly seen.

135 *H.A.*, II, 12; 503 b 20. He describes respiratory and other movements after the creature is cut open.

philosophical phenomena in a biological fashion,[136] it is beyond need of proof that he viewed biological phenomena from a philosophical standpoint.

Thus it could be argued that when dealing with the location of the brain, he is reasoning *a priori,* a technique which Lewes[137] and others often accuse Aristotle of using in his scientific writings. As Karsch[138] has suggested, he may have argued that as hearing is made possible by air, thus, just as he had found the element water in the eye and in the brain, he must now find air in the head. He therefore invented the occipital space for the needs of his theory of hearing. In other words, he was led to his assertions concerning the occipital space by theoretical considerations only.[139] On the other hand, it would be possible to suggest that Aristotle's assertions which have been discussed could have been the product of some thought process or belief of which we now have no trace.

But it seems that neither the empirical nor the purely speculative approach explains adequately all aspects of the problem, and that a combination of the two is a more satisfactory conclusion. Thus it is suggested that to the knowledge of the human brain handed down to him by his predecessors, Aristotle added a complexity of observational data derived from the dissection of lower animals and in particular perhaps from reptiles such as the turtle and the chameleon and from fish. He was then able to interpret this evidence according to his philosophical requirements so that they fitted into the closely reasoned theory of brain and special sense organ function. As he indicates, structural details are of less importance in themselves than the relation of such parts to the total form, for they have no independent existence. Anatomical errors were therefore of less significance to him than to the modern biologist and they did not necessarily interfere with his general thesis.

This attempt to reconstruct Aristotle's thought processes is made with the full knowledge that such a practice is singularly hazardous, and also with the realization that those who indulge in it may discover that instead of following Aristotle's line of argument as they intend, they are, in fact, following their own.

136 Randall (*op. cit.* [note 28], p. 224) has recently stressed the biological motivations of Aristotle's thought, and he takes into account the similar conclusions of Thompson (*op. cit.* [Note 81], p. 80). Peck (*op. cit.* [note 44], p. 1), and Hantz (H. D. Hantz, *The biological motivation in Aristotle.* New York, Columbia University [Ph.D. Thesis], 1939).

137 *Op. cit.* (note 48).

138 *Op. cit.* (note 38), p. 54.

139 One could perhaps argue that at times Aristotle's philosophy dictated his physiology (*P.A.*, II, 7; 653 b 3).