Visual Prototypes

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Abstract

In this paper I introduce the concept of "visual prototype" to capture one particular kind of work done by visual representation in the practice of science. I use an example from neuroscience; more particularly, the example of the visual representation of the pattern of convolutions (the gyri and sulci) of the human cortex as this pattern is constructed and used in the practice of mapping the functional human brain. I argue that this work--which is visual representation as distinct from linguistic representation--is an essential piece of the human brain mapping project.

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Note: Because of the visual nature of this article (i.e. the large number of figures necessary to the argument), it is perhaps not suitable for publication in *Philosophy of Science.* The present version of this paper is designed for presentation (with transparencies). A different version could be prepared for publication.

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Introduction

In current philosophical discussions there appears to be general agreement that it is misleading to characterize scientific knowing as a fundamentally linguistic practice. Implications from two distinct paths of investigation--work in the philosophy of science on the nature of scientific theories and / or models, and work in philosophy of mind on the nature of representation--are converging on the importance of non-verbal practices in the discovery and construction of scientific knowledge. This general agreement is bringing needed philosophical attention to the pictures, diagrams, and visual images of all sorts that are typically found in scientific publications. However, as yet, there is little agreement as to *why* these visual images are important, or *how* they are involved scientific knowing. What might be helpful now are descriptions and analysis of very specific *work* done by visual representation in very specific scientific practices. This paper is an attempt to present an example of such work--visual prototype construction in neuroscience--in a way that might deepen the general view of the importance of pictures to the practice of science.[1]

One way to approach the study of visual representation in science is to try to expand our view of scientific *languages* to include the non-verbal representational practices of graphs, drawings, photographs, etc.. This approach emphasizes the language-like qualities of scientific visual representation.[2] Another possible approach is to point to certain elements of scientific practice which are non-verbal, but which are nonetheless cognitive, communicative, and representational. Rather than stretching our view of language to include non-verbal elements, this second approach tries to expand our view of scientific thinking, scientific communication, and even scientific claims and theories, to include non-verbal, non-linguistic elements.[3] One problem with this approach is the fact that the verbal and the visual--language and visual representation--are highly integrated in actual scientific practice. It is very difficult, and perhaps not ultimately useful, to try to completely isolate the verbal from the visual. However, given the fact that the verbal and the visual are interwoven in the practice of science, and the fact that philosophy has a history of analyzing the practice as thoroughly linguistic; it is necessary to show

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1 See Shelley 1996 for the example of visual abduction in archaeology.

2 Martin Rudwick takes this approach (see Rudwick 1976 as an early example which initiated this discussion in the history of science).

3 Rudolf Arnheim's views on visual thinking are central to this approach.

what visual representation *adds* to the practice. In this context, I am trying to show the non-language-like aspects of pictorial thinking and pictorial communication.

In this paper I take this second approach to the study of one kind of visual representation found in the practice of neuroscience--pictures of the human brain. I introduce the concept of *visual prototype* to capture the role of these particular pictures. I argue that these pictures provide evidence for high level cognitive activity (e.g. abstraction, generalization, and category construction) which is non-linguistic (i.e. not in any natural language) and yet is representational--it is *about* the brain. This activity is not only individualistic (inside individual heads), but it is distributed or social. Communication is a major function of the visual representations I will be looking at.

Constructing Visual Prototypes

In psychology, Eleanor Rosch and her colleagues have convincingly shown that humans, in their everyday cognitive practices, sort objects in the world into categories constructed around prototypes. They argue that such category construction works from the inside out, rather than from the outside in. Rather than being circumscribed by well defined boundaries, categories have an "internal structure" that is "composed of a 'core meaning' which consists of the 'clearest cases' (best examples) of the category, 'surrounded' by other category members of decreasing similarity to that core meaning" (1973, p. 112). The internal structure of common object categories is based on such things as: common attributes, motor movements in common, objective similarity in shape, and identifiability of averaged shapes (1978). In practice, "categories tend to become defined in terms of prototypes or prototypical instances that contain the attributes most representative of items inside and least representative of items outside the category" (1978, p. 30).[4]

Rosch et al are concerned with categorization as it happens within a culture in daily life, and to the extent to which scientists also live within such cultures, her model can be seen as applicable to scientists. However, it is an additional question to ask whether Rosch's model applies to category formation within the practice of science. It is possible that the classical model of categorization (logical, bounded entities) is true of scientific practice, whereas the non-classical (Roschian) model is true of everyday cognition. Several philosophers of science (e.g. Giere 1994, Nersessian 1992, Bechtel & Abrahamsen 1990) have recently used Rosch's work to argue that this non-classical model fits scientific practice better than the classical model.

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4 Arnheim made a similar point in 1969. He drew the distinction between container concepts and types: “A container concept is the set of attributes by which a kind of entity can be identified. A type is the structural essence of such a kind of entity." He then argues that "The abstraction characteristic of productive thinking are types rather than containers--in science as well as in art” (1969, pp. 174-175). An example of type vs. container concept: “the container concept of intelligence as the set of persons capable of tackling certain test questions [versus] the type concept of intelligence as a structural pattern of mental behavior” (1969, p. 178).

My intent here is to extend Rosch's insights to the study of the role of visual representation in science and to argue that a primary function of visual representation in science is in the construction of visual (visuospatial)[5] prototypes and visual (visuospatial) prototypicality. If we understand the extent to which scientific categories are held together by internal structure rather than surrounded by well defined boundaries, then we might see more clearly the prominent--even, essential--role of visual representation in the discovery and construction of scientific categories.

Using a specific example in neuroscience, I will argue that certain practices of visual representation involve the construction of visual prototypes which form the internal structure of 'Roschian' categories. Where Rosch needed to show that people in her laboratory experiments actually used prototypes rather than external boundaries, I will try to show that the practice of mapping the brain uses visual representations for the explicit and purpose of constructing the prototypical brain as a necessary prerequisite for mapping the brain. One reason that scientists construct and use visual prototypes may be that their everyday cognition uses Roschian prototypes. Another reason may be that visual imagery is, as argued by Kosslyn (1994) and others, a major part of everyday cognition. But an additional reason--the

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[5] Although I will continue general practice by referring to the graphic representations in science as "visual representation" it is more accurate to see these representations as visuospatial such that the third dimension of 3-D renderings is also included in the class.

one I want to explore here--is that visual representation is the most appropriate kind of representation for this particular *scientific* purpose.

The visual representations that I am investigating are external, materialized objects such as drawings or photographs. As distinct from the internal mental processes and images studied in cognitive science, the external, materialized visual representations constructed and used in the practice of science are visible, tangible, public objects. These objects function within the social context of scientific practice both as elements of distributed cognition and as significant vehicles of communication amongst scientists (and to the public beyond). Rosch's questions can be asked of these visual representations and representational practices. For example, do neuroscientific textbooks use visual representations of prototypes in the teaching of categories, or do they use definitions and descriptions of boundaries? Is there a public (i.e. not privately mental) practice of prototype construction that can be observed and analyzed as a distinct process? Are visual representations involved in this practice? Can particular visual representations which are used repeatedly be seen as prototypes or focal points in category construction?

Human Brain Mapping

A very active area of current neuroscientific research is the functional mapping of the human brain. This mapping endeavor is primarily focused on the cerebral and cerebellar cortex and is motivated by the current theory of cortical localization which claims that areas of human brain cortex are specialized for different mental functions: distinct mental functions are performed by distinct sets of neurons. Within this general claim, there is a wide range of views about how a particular function such as language might be arranged in the brain (e.g. as a number of relatively small groups of neurons distributed over a relatively large area of the brain, or as one or two larger groups of neurons localized to two sites such as Broca's and Wernicke's areas). The overwhelming challenges of this research are, so to speak, to carve the mind and the brain at their natural joints such that particular parts of the mind are the right sorts of thing to localize in the particular places identified in the brain.

The history of this scientific research program is best characterized as the history of a practice rather than the history of a theory. It would be false to say that the claim of cortical localization that is now standard doctrine in neuroscience has a history that goes back to ancient Greece and Egypt. However, the *practice* of locating mental functions in specific locations within the head does have that history. The linguistic claims made within the practice have radically changed throughout this history, but the practice of brain mapping has a definite continuity. In early European writings of the Middle Ages, for example, the different mental functions were thought to be "common sense," "imagination," "reasoning," and "memory."

And the different locations were the ventricles or spaces (thought to be empty) within the brain. Thus, the claim was that a mental function was "performed in" a particular part of the brain. These mental activities, which were not physical processes at all, took place within the empty cells within the brain. Today, on the other hand, the differentiation of mental functions to be located in the cortex alone is in a state of great proliferation. There is no single list of mental functions that everyone in the field would agree on, and any list that named all the functions being looked at would be very long and would have many areas of overlap and contradiction. Also, the number of locations within the brain is limited only by the scale at which one is working. The meaning of "performed in (or by)" or "specialized for" is also currently understood in several different ways, and all of them very different from the medieval view of non-physical functions happening in empty spaces within the brain. However, throughout the history of the practice of brain mapping the focus has been on the same question, “What area of the brain can be identified with--or simply associated with--what mental function?” The goal of this practice is some sort of map or atlas that locates individual mental functions in particular anatomically defined parts of the human brain. This practice has been going on since, at least, 300 BC in Greece.

Toga & Mazziotta, in their book *Brain Mapping*: *The Methods*, describe the cartography of the brain as fundamentally similar to cartography of the earth.

"Whether the cartographic topic is a description of a shoreline or the boundaries of the basal ganglia, the fundamental issues are the same" (1996, 3). The objective is to construct good maps which "represent reality as we know it" (1996, 3). This analogy has been adopted by the field and the name "brain mapping" is now used throughout the practice. There is a journal called *Human Brain Mapping*, another called *BrainMap*, an annual conference called "The International Conference on Functional Mapping of the Human Brain," and a recently formed professional organization: Organization of Human Brain Mapping.

Although the metaphor of "mapping" is very apt, there is one very significant way in which mapping the brain is not like mapping the earth. Cartography has as its goal the localization of significant geographical features on our one and only home planet--Earth. Functional brain mapping, on the other hand, has as its goal the localization of significant neurological functions on the physical anatomy of *all* human brains, *any* human brain, or *the* human brain. As Toga & Mazziotta put it, "neuroanatomy must represent a variable physical reality that differs from individual to individual" (1996, p. 389). Knowing the kind of variation and the amount of such variation that exists among individual human brains is an essential piece of the brain mapping project. This problem is certainly not new, nor is it unique to the human brain. The point that I want to make here is that visual representation has a major role in the discovery and construction of this kind of knowledge. The visual representation of both the commonality and the variation among brains is a necessary part of the process of constructing *the* human brain.

Visual Prototypes of the Brain

The history of brain mapping, or functional localization, has been written by several individuals; however, one of these histories is particularly useful to the present study: *An Illustrated History of Brain Function*: *Imaging the Brain from Antiquity to the Present* by Edwin Clarke and Kenneth Dewhurst originally published in 1972. This book is rare in the history of science in that it gives full recognition to the significant role of visual representation in the discovery and construction of scientific knowledge.[6]

Here I will focus on the evolution of imaging the cerebral convolutions: the pattern of sulci and gyri of the brain. Clark & Dewhurst characterize the evolution of these visual images as a progression towards increasingly naturalistic depiction: the depictions become more accurate, more realistic, conforming more closely to nature. In repeating this story here, my intention is to critique some of the basic assumptions held by Clarke & Dewhurst. Although, I appreciate their focus on visual representation, I think they have missed some of the key aspects of how

6 Current works, such as Rudwick 1992, are changing this situation.

visual prototype construction works in practice.

The progressive story is one that is told--and can only be told--in retrospect from within the particular perspective of current knowledge: the history is understood as a progression towards the present state of knowledge. Current knowledge is that the cerebral cortex is a highly complex functional structure. All of the higher cognitive faculties (motor control, visual processing, sensory processing, consciousness, memory, language, etc.) are currently attributed to the cerebral cortex and the cerebellum. The cerebral cortex is a convoluted or folded sheet of neurons whose axons extend out of the inner side of this layer towards the center of the brain. The cerebral cortex is thus the convoluted outer surface (after removal of the skull, blood vessels, cerebral-spinal fluid, and several layers of tissue.

It is thought that the highly convoluted nature of the cortical sheet "arose during evolution of the primate brain as the volume of the cerebral cortex increased more rapidly than the volume of the cranium" (Kandel et al, 1991). However, the causal processes involved in the formation of the exact folds or pattern of sulci (crevices) and gyri (crests) are still an open question. The pattern of cerebral convolutions is thought to be standard enough across different human brains to warrant naming certain gyri and sulci, and these features (e.g. the central or Rolandic sulcus, the precentral gyrus) are considered landmarks of the standard brain. It is also generally thought that these landmarks are places or structures in which functions can be. That is, it is currently thought that there is a relationship between the folding pattern of the cortex and the location of certain functions within the cortex. For example, it is said that motor functions are located in the precentral gyrus: the precentral gyrus is often called the motor strip. Thus the representation of the pattern of gyri and sulci in "the human brain" is fundamental to the functional mapping of the human brain.

Taking current knowledge about the significance of the convolutions as a given, we can now look back to see when these scientific objects were first visualized. Clarke & Dewhurst found some 13th century representations of brain function which show wavy lines in the area of the brain (see Figure 1), but it would be difficult to argue that they are intentional representations of the pattern of cerebral convolutions. Leonardo da Vinci drew a sketch of the surface of an ox brain (see Figure 2) in which a convolution pattern can be identified: current knowledge tells us that this sketch is a depiction of an ox's brain even though da Vinci does not identify it as such. The sketch is dated between 1504 and 1507, but da Vinci is an historical anomaly in this story (as he is in other histories of art and science). Generally speaking, illustrations prior to the early 19th century depict the cortex without any specific pattern. In naturalistic pre-19th century illustrations the cortical surface is depicted to look like "coils of small intestine" (as described by Erasistratus in the third century BC.) or "a plate of macaroni" as a later observer noted. A few of the illustrations used by Clarke & Dewhurst are included here in Figure 3. As Clarke & Dewhurst argue, prior to the end of the 18th century, even though there were many advances in the techniques of illustrating, "the idea of a definite pattern with named gyri and sulci had yet to be established" (1996, p. 85). It is important to note that this yet to be established "idea" must be seen as both a linguistic idea and as a visual idea: the convolutions were not named, but also their pattern had not been visualized. Towards the end of the 18th century, several drawings stand out as increasingly "realistic," or conforming to nature, as Clarke & Dewhurst put it (see Figure 4). Clarke & Dewhurst attribute this advance to artistic trends which were interacting with anatomical illustration practices generally.[7]

It was not until Franz Joseph Gall (1758-1828) introduced the "science" of cranioscopy or phrenology that the pattern of gyri and sulci was fully recognized. Gall postulated that the brain was the organ of the mind with mental and moral faculties located in specific areas of its surface. The individual locations were also called organs and Gall identified 27 of them (see Figure 5, top). There is a distinct lack of empirical evidence in the historical material that would justify Gall's delineation and localization of the faculties, or his assumption that there was a direct correlation between the size of a particular organ and the wealth of that

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7 This same story is told in other case studies within the history of science. See, for example, Edgerton 1991 and Rudwick 1992.

particular faculty in a person's character. He argued that the outer shape of the skull reflected the sizes of the various mental organs. Thus, an excess or a deficit of a faculty could be detected by examining the skull. A bump on the skull, depending on where it was located, might mean an excellent capacity for memory, or it might mean an excess of covetousness. An indentation would indicate a deficit in one of the faculties. It is interesting to note that these faculties are sometimes moral goods (love of offspring), sometimes neutral (memory, sense of place), and sometimes moral evils (tendency to murder). Thus a bump on the skull can be a good thing or a bad thing depending on where it is located. Following Gall, others identified up to 160 different such organs including things like republicanism, faithful love, and submissiveness.

Gall's so-called "cult of cranial bumps" (Clarke & Dewhurst 1996, p. 104) was later completely discredited by the neuroscientific community, however his work is also seen as the first instantiation of the current theory of cortical localization and as the beginning of the modern practice of functional mapping of the human brain. Now that functional localization is accepted doctrine, Gall's contributions are being revisited. In reference to one of Gall's illustrations (see Figure 5, bottom) Clarke & Dewhurst argue that

> by placing the numbers of his organs directly on the convolutions of the brain as well as on areas mapped on the surface of the cranium [Gall] brought together our two main themes: localization of brain function and the morphological arrangement of the cerebral gyri. We have finally arrived at a

> theory of localized function of the cerebral convolutions. (Clarke & Dewhurst 1996, p. 98)

Clarke & Dewhurst argue that "the late 18th century anatomists were beginning to depict the cerebral gyri with scrupulous care and artistic talent, even though there seemed little reason, from a functional point of view for such minute attention" (1996, p. 104). Gall's system transformed this activity into "an urgent and meaningful desire to know more about the convolutions and sulci" (1996, p. 104). By the middle of the 19th century, due to developments in macroscopical, embryological, and comparative anatomy, "the chaos of cerebral convolutions [was transmuted] into an orderly gyral pattern" (1996, p. 104) in both human and animal brains (see Figure 6). What Clarke & Dewhurst call "the final phase of unraveling, defining, tracing and naming the cerebral convolutions" (1996, p. 110) shows the beginning of a return to more schematic drawings (see Figure 7). Clarke & Dewhurst do not point this out, but the shading that in the previous "realistic" drawings indicated the convex shape of the gyri, has been dropped. The lines that indicate the sulci give a certain amount of depth to the drawing, but the drawings seem to be aiming for a more abstract representation of the gyri and sulci than the previous drawings. The location of the lines has become more important than the texture of the surface. My own interpretation of this progression is that once the significant structural elements of a natural object have been identified, then the emphasis on realism, naturalism, and artistic merit is relaxed. Once the community has been convinced that these particular structural elements are "real" (they are significant, they matter, they exist over multiple examples in nature, they constitute a pattern in nature) then it is no longer necessary to portray them with realistic clues or naturalistic embellishments. When the community is convinced, the "facts" no longer need to be depicted convincingly. See Figure 8 for an example of the very abstract--yet accurate--representations of the cerebral convolutions used in contemporary texts.

The Clarke & Dewhurst story of the progressive depiction of the convolutions ends with a reference to photography as the ultimately realistic and naturalistic method of representation of the cortical surface. However, it is very interesting to read, in their caption under a photograph of the cerebral surface as seen in life during brain surgery, the following statement. "Many will agree that there *is* a faint resemblance to the abdominal contents of an animal with its tight packed coils of ileum, which brings us back full circle to Erasistratus in the third century BC." (1996, p. 113, emphasis in original). This comment, and looking at the photograph (see Figure 9), seems to indicate that contrary to what Clarke & Dewhurst say, photography is not the ultimate in scientific illustration. Instead, realistic, naturalistic scientific illustration has its place, but schematic illustration is always necessary. Each individual viewer has to learn to see the abstracted pattern in the actual object. This requires the education or training of one's visual system. Clarke

& Dewhurst have cut the story short by focusing on one piece of the history and taking for granted the many schematic drawings and models of the cerebral convolutions that follow that piece of the history. The story continues with these schematic drawings in which the cerebral convolutions are clearly represented with little or no concern for realism. However, at the same time, the story also continues with new kinds of "realistic" representation (x-ray, neuroimaging) that go beyond photography of the surface of the brain.

An alternative approach is to frame the story as the development of a visual representation of "*the* human brain:" the *prototypical* human brain. This visual representation--or complex set of visual representations--includes both schematic and naturalistic representations. Criteria for which kind of visual image might be useful in a given context depends on the purpose of the immediate practice. Of course, some of these images are "realistic" (photographs, neuroimages), but these images must be accompanied by visual abstractions which instruct the viewer on how to see the realism in the images. Even the most naturalistic scientific illustrations are not transparent windows on reality. All of these visual images are *representations* of the brain.

Recent developments in neuroimaging technologies--positron emission tomography (PET), and functional magnetic resonance imaging (fMRI), for example--offer new ways of visualizing *individual* functioning human brains.

These technologies also give rise to new challenges for integrating data from individual brains into knowledge about *the* functional human brain. There are currently two distinct approaches to constructing atlases of brain function: the average brain atlas versus the probabilistic atlas. Evans et al (1996) describe the difference between these two approaches as the difference between removing anatomical variation and quantifying it. They argue for the probabilistic approach and are developing an atlas which attempts to visually quantify MRI and PET data over more than 300 individual brains (see Figure 10 & 11). Woods (1996), on the other hand, argues for the use of the average brain atlas. "A brain that minimizes the average amount of distortion required to register it to any individual in the population is an ideal choice to serve as a target atlas for that population" (1996 p. 336). Woods offers several different ways of visualizing the extent of the variation. Figure 12 gives a clear impression of the problem, but does little to quantify it. Figure 13, on the other hand, attempts to give a more quantified sense of variation of location of specific sulci.

The current state of development of brain atlases offers a preview of the continuation of the story. Having established the commonality of features such as the sulci and gyri in *the* human brain, the science has now moved into a phase of reestablishing the variability of these features. It is very difficult to say, at the moment, where this story will go from here. Various on-line atlases or databases are in a state of rapid development and testing. For example, Evans's group in Montreal has recently created an "on-line interface to a 3D MRI simulated brain database" called BrainWeb. Their hope is that the database will serve as a "gold standard" for the brain mapping community. The future of the visual prototype of the brain appears to be in virtual cyberspace.

Conclusion

The purpose of this survey of only a very small percentage of the pictures of the brain used in the practice of functional human brain mapping has been to show some of the work that goes into the construction of visual prototypes in at least one scientific practice. Whole technologies are developed (from perspective drawing through computer visualization) for the purpose of creating stable, exemplary, comprehensible images of the prototypical brain. Practices such as the localization of specific functions in specific parts of the brain require the construction of these visual representations, not only for the individual cognitive tasks of figuring out what goes where, but also for the distributed (social) tasks of coordinating research among communities of scientists.

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FIGURE 48
This is one of the most popular portrayals of the Cell Doctrine. In 1503 Gregor Reisch (c. 1467–1525) a Carthusian prior of Freiburg and Confessor to Emperor Maximilian I, published his compendium of grammar, science, and philosophy, *Margarita philosophica*, the first notable modern encyclopedia.[16] This drawing appeared in it[17] and has been reproduced on many occasions since.

There are three freely communicating cells: the first is inscribed "sensus communis, fantasia, imaginativa", the second "cogitativa, estimativa", and the third "memorativa". The special sense organs are connected with the first cell and between it and the second is the word "vermis". To the modern anatomist this refers to the mid-line portion of the cerebellum, thought by Galen to act as a valve between the third and fourth ventricle (see Figures 24, 25, 39, 57). In the present context, however, it is applied to the worm-like choroid plexus as it passes through the foramen of Monro and controls the flow between cells one and two. Manfredi in his *Anothomia* of 1490 described it in this location and stated that thinking is arrested when it blocks the passage and begins again when it unblocks it.[18]

The patterning around the cells may conceivably be intended to portray cerebral convolutions.

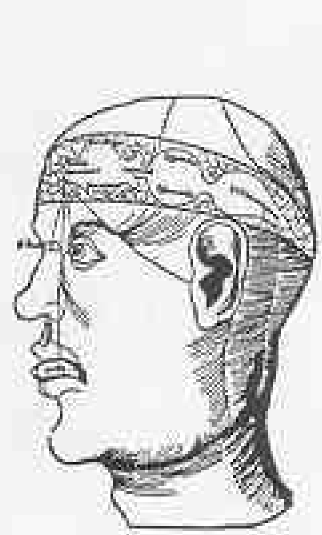

FIGURE 48

FIGURE 49
Reisch's drawing was soon plagiarized and a sequence of publications from the 16th to the 19th centuries contained various forms of it. One of the first was in the 1523 edition of a book by Ramon Lull (c. 1235–1315),[19] *Practica compendiosa artis*,[20] in which the illustrations were drawn by Guillaume Leroy II, the son of Lyons' first printer.

FIGURE 49

Figure 1: Early depictions of brain function that show wavy lines in area of cerebral cortex. (Clarke & Dewhurst 1996, p. 38)

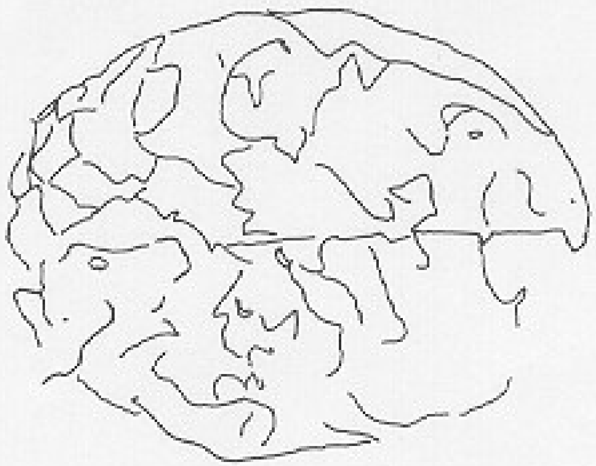

FIGURE 79

The appearance of the cerebral convolutions was first described by the Ancient Egyptians,[2] but the earliest pictorial representation so far discovered seems to be that seen already in Figure 22, dating from 1345. This pencil sketch seen here from the same leaf of Leonardo da Vinci's notebooks as Figures 67 & 72, dated between 1504 and 1507 is less vague. A convolutional pattern can be detected with certainty[3] and by the identification of certain gyri it has been suggested that the brain is that of an ox, seen from above.[4] This then is the first certain drawing of the cerebral convolutions, although probably not those of man.

Figure 2: Possibly the first depiction of a brain convolution pattern. (Clarke & Dewhurst 1996, p. 65)

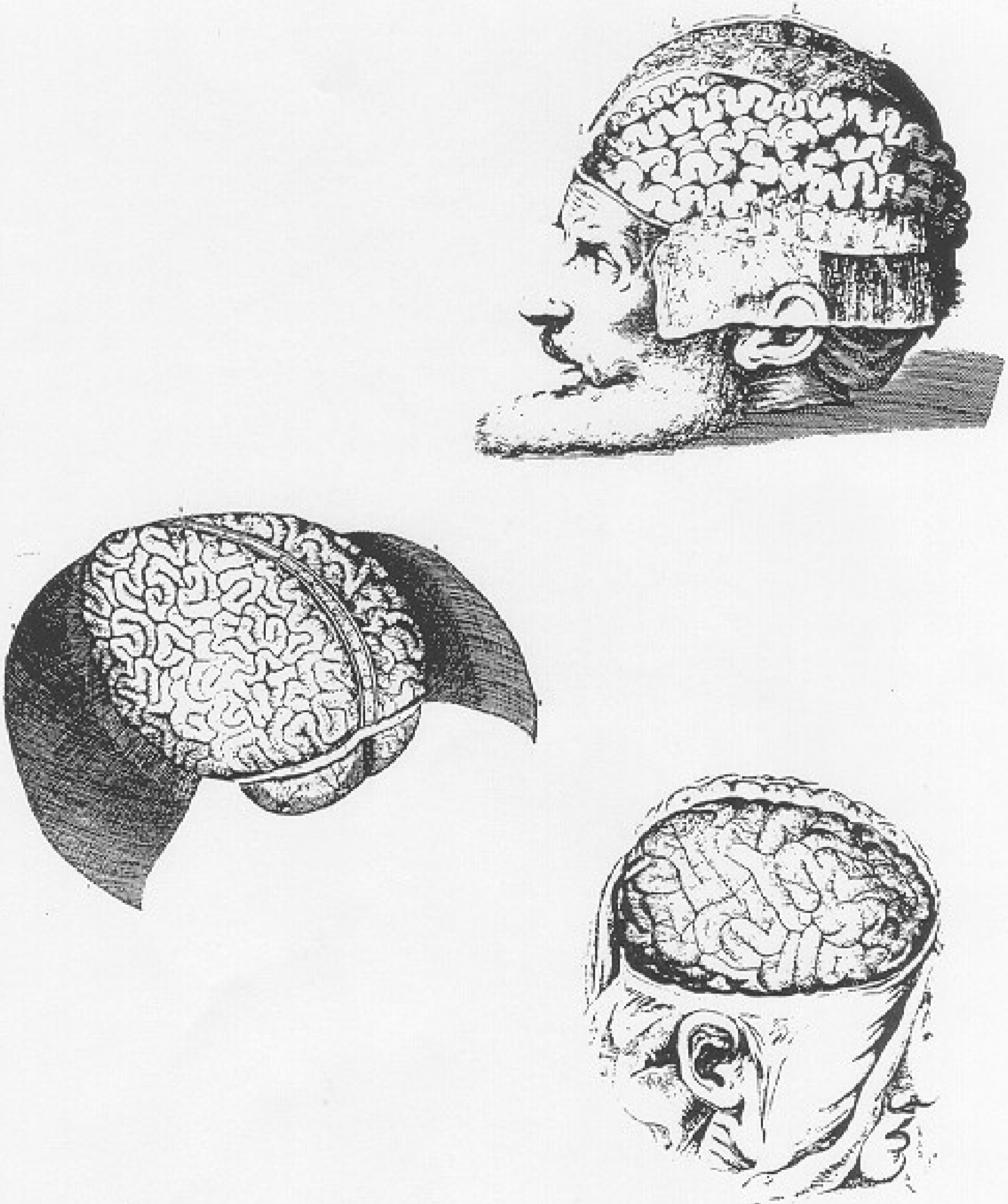

Figure 3: Some examples of drawings of the cerebral cortex that are "drawn according to a preconceived idea rather than in keeping with its morphological appearances revealed by direct inspection" (p. 70). (Clarke & Dewhurst 1996, p. 70, 87, & 91)

FIGURE 111
Eleven years after the death of Vicq d'Azyr, a collected edition of his works appeared containing this drawing of the brain.[44] Although there is some conformation to nature as in Figure 110 the convolutions still look like coils of intestine. Whether Vicq d'Azyr himself would have allowed this plate to be published cannot be determined but it does show that the old Erasistratian analogy (p. 60) seems to have persisted until 1805 at least.

Unlike his predecessors, Vicq d'Azyr examined the cerebral surface carefully instead of ignoring it. He enumerated anterior (1, 2), middle (3, 3, 4) and posterior (7, 7, 7) lobes of the cerebrum which Haller preferred to term frontal, parietal and occipital regions respectively.[45] Vicq d'Azyr also described some of the lobes' constituent convolutions: "convolution that follows the corpus callosum" (20, 24, 26, 27); "the convolution that follows this one" (18, 22, 9, 9, 19); etc. Artistically this plate is inferior to that of Soemmerring (Figure 109), executed 9 years earlier, but from the anatomical point of view it was an important advance directly stimulating the researches of the French anatomists who will be discussed in Chapter 11.

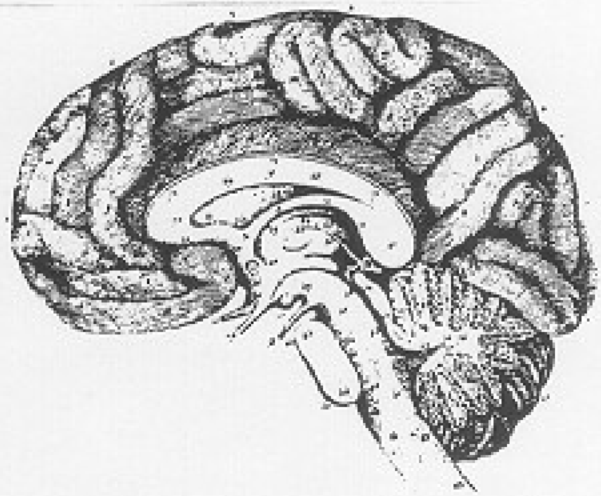

FIGURE 111

FIGURE 112
Charles Bell (1774–1842),[46] the famous British anatomist and surgeon, at about the same time was content to accept the three divisions of the brain. In his lengthy legend to this plate he did not make any special comments on the gyri.[47] The importance of this plate is as an accurate portrayal of the cerebral gyri drawn by Bell himself and engraved by T. Medland.

Together with those of Soemmerring and Vicq d'Azyr it characterizes the pre-scientific era of the anatomical investigation of the cerebral convolutions. Anatomists tended to depict structure as faithfully as they could but were not primarily concerned with a scientific attack on the problem for they were not approaching function by way of morphology. This was to be their role during the later decades of the 19th century.

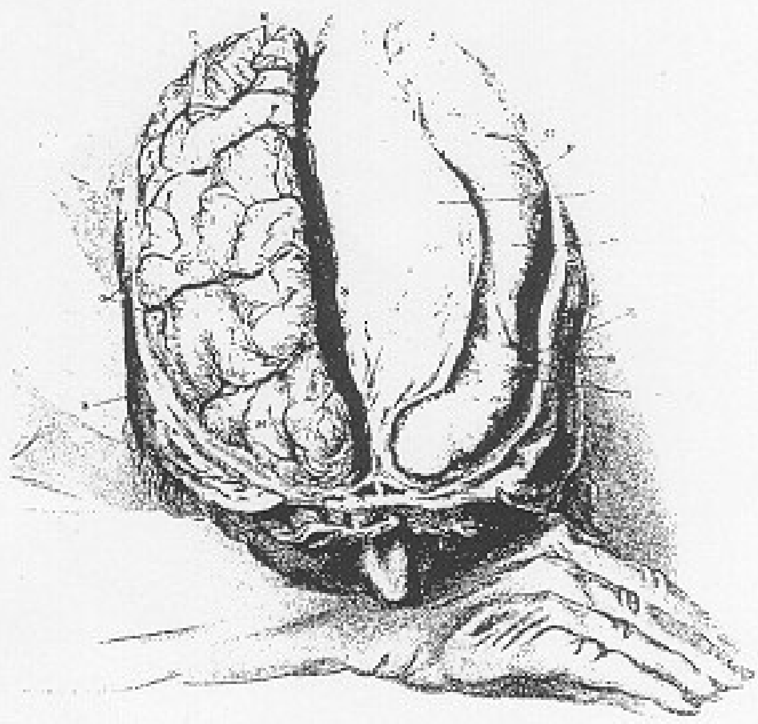

Figure 4: Two transition drawings that show development towards a more realistic rendering. (Clarke & Dewhurst 1996, p. 91 & 92)

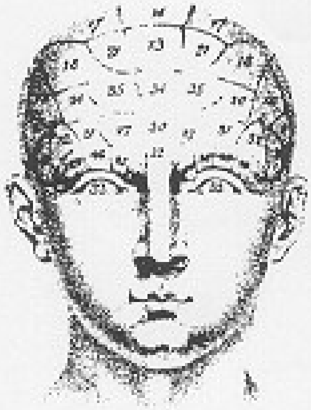

FIGURE 116
Of the two, Gall was the originator of phrenology and a skilled anatomist, whereas Spurzheim although an able dissector of the brain did more to publicize and, for a time, to promote the discipline. He travelled widely to spread the gospel and died in harness during a lecture tour of the U.S.A. However, he modified the system by adding another eight organs, and his schema became more popular than Gall's original.

This drawing is from a book published by Spurzheim in 1825[9] and the numbers again refer to the "powers and organs of the mind". Their listing is unnecessarily detailed for our purposes.

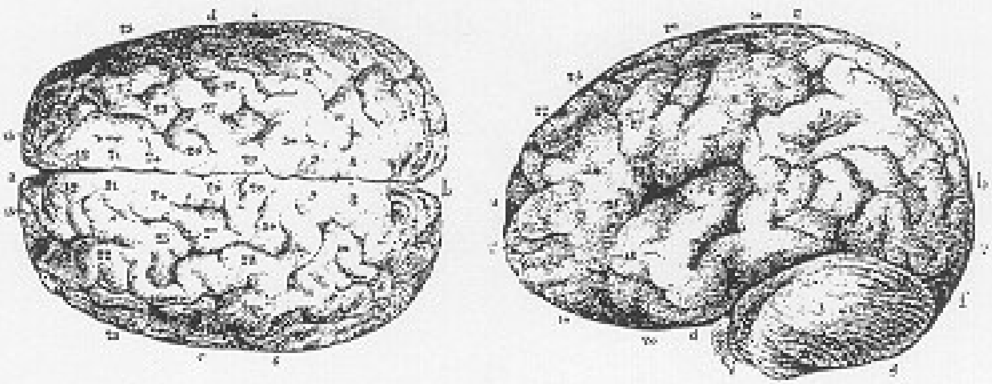

FIGURE 118
As will be seen in the next chapter, Gall in 1810 by placing the numbers of his organs directly on the convolutions of the brain as well as on areas mapped on the surface of the cranium brought together our two main themes: localization of brain function and the morphological arrangement of the cerebral gyri. We have finally arrived at a theory of localized function of the cerebral convolutions.

Figure 5: Early phrenological drawings of brain function. (Clarke & Dewhurst 1996, p. 98 & 99)

FIGURE 129
Meanwhile considerable advances had been made by macroscopical study of the convolutions. The fissure of Sylvius was the first sulcus to be identified and named (Figure 90). The island of Reil or insula, clearly depicted by Bartholin (Figure 90) in 1641, was described in detail by Johann Christian Reil (1759–1813) in 1809.[16] They were the first two landmarks to which was added in 1831 the fissure of Rolando.[17] Figure 129 shows it clearly, together with other sulci and the gyri on the lateral surface. The numbering relates to phrenological "organs" so we can assume Rolando had not advanced in his ideas of function. Nevertheless he forecast correctly the discovery of regularity in shapes and sizes of the gyri. It was Rolando who used the term "enteroid processes", as had his teacher (p. 104).

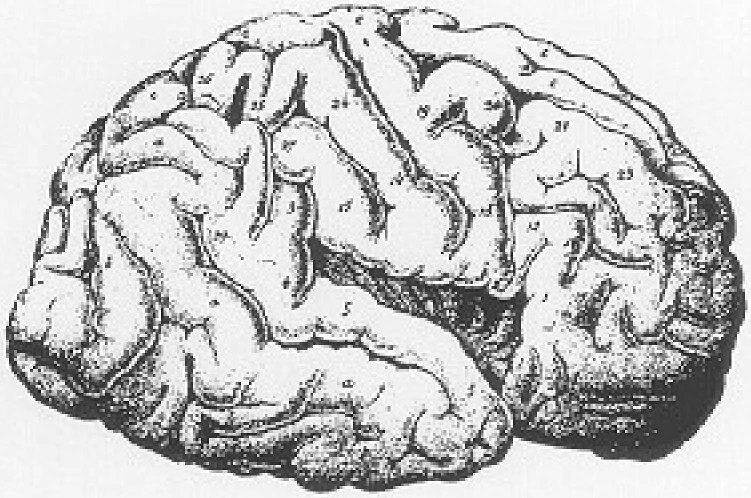

FIGURE 131
Another excellent plate of the cerebral convolutions is from the second volume of *Anatomie comparée* (1857) in which Gratiolet summarized his views.[21] It was prepared under the direction of Lauret who, however, died six years before its publication.[22] Again there is precise labeling of gyri and sulci.

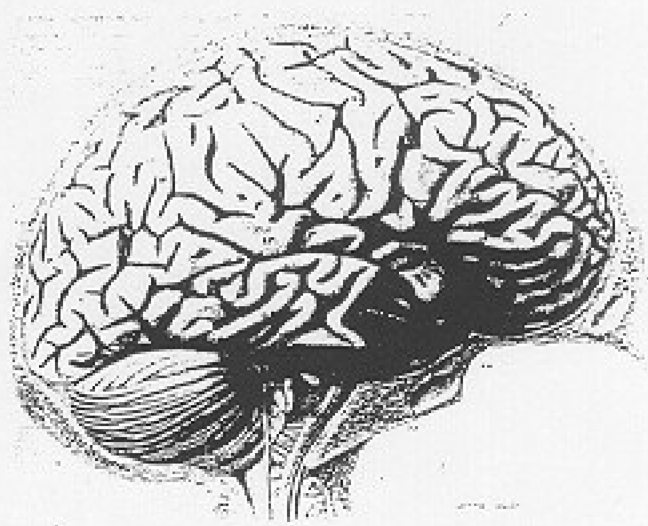

FIGURE 131

Figure 6: Two drawings that arrive at a depiction of an "orderly gyral pattern." (Clarke & Dewhurst 1996, p. 108 & 109)

FIGURE 133
The final phase in the process of unravelling, defining, tracing and naming the cerebral convolutions was carried out by a Scot and a German. The former, William Turner (1832–1916) Professor of Anatomy in the University of Edinburgh,[25] published his researches in 1866.[26] He redefined the limits of the cerebral lobes, and generally supplemented Gratiolet's detailed studies by, for example, establishing the fissure of Rolando as the posterior limit of the frontal lobe. Figure 133 illustrates some of his work.[27] Darwinian evolutionary theory must now be considered in relation to the correlation between the gyral patterns of animals and man with intelligence, a problem which is still unresolved.[28]

FIG. 1.

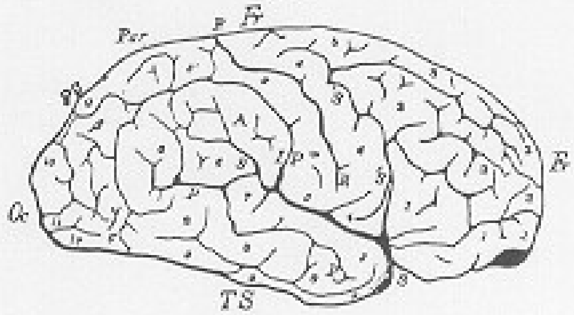

FIGURE 134
The German anatomist was Alexander Ecker (1876–1887) of Freiburg,[29] who, with obsessional exactitude gave an even more detailed account than Turner of the gyri and sulci. His little book of 1869[30] greatly contributed to the dissemination of his ideas which became better known than Turner's there was an English translation in 1873.[31] In Figure 134 the main sulci and gyri are named; "F" is for frontal, "T" temporal, etc.[32]

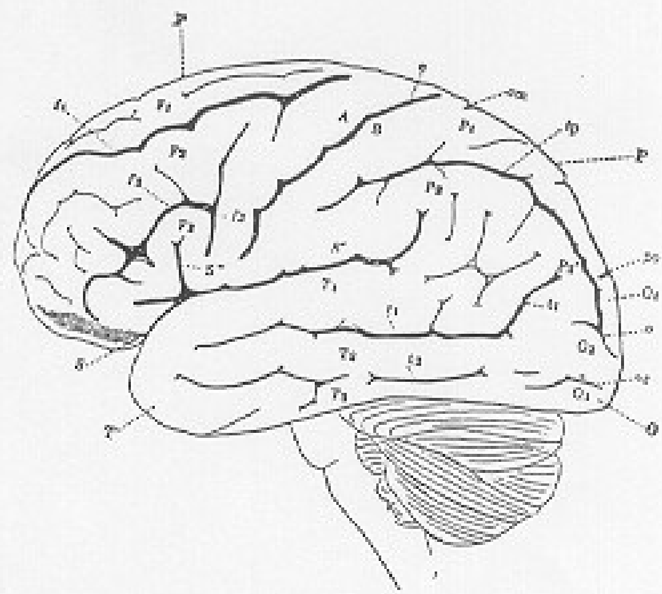

Figure 7: Two drawings that show the return to a more abstract, less naturalistic depiction of the gyral pattern. (Clarke & Dewhurst 1996, p. 111 & 112)

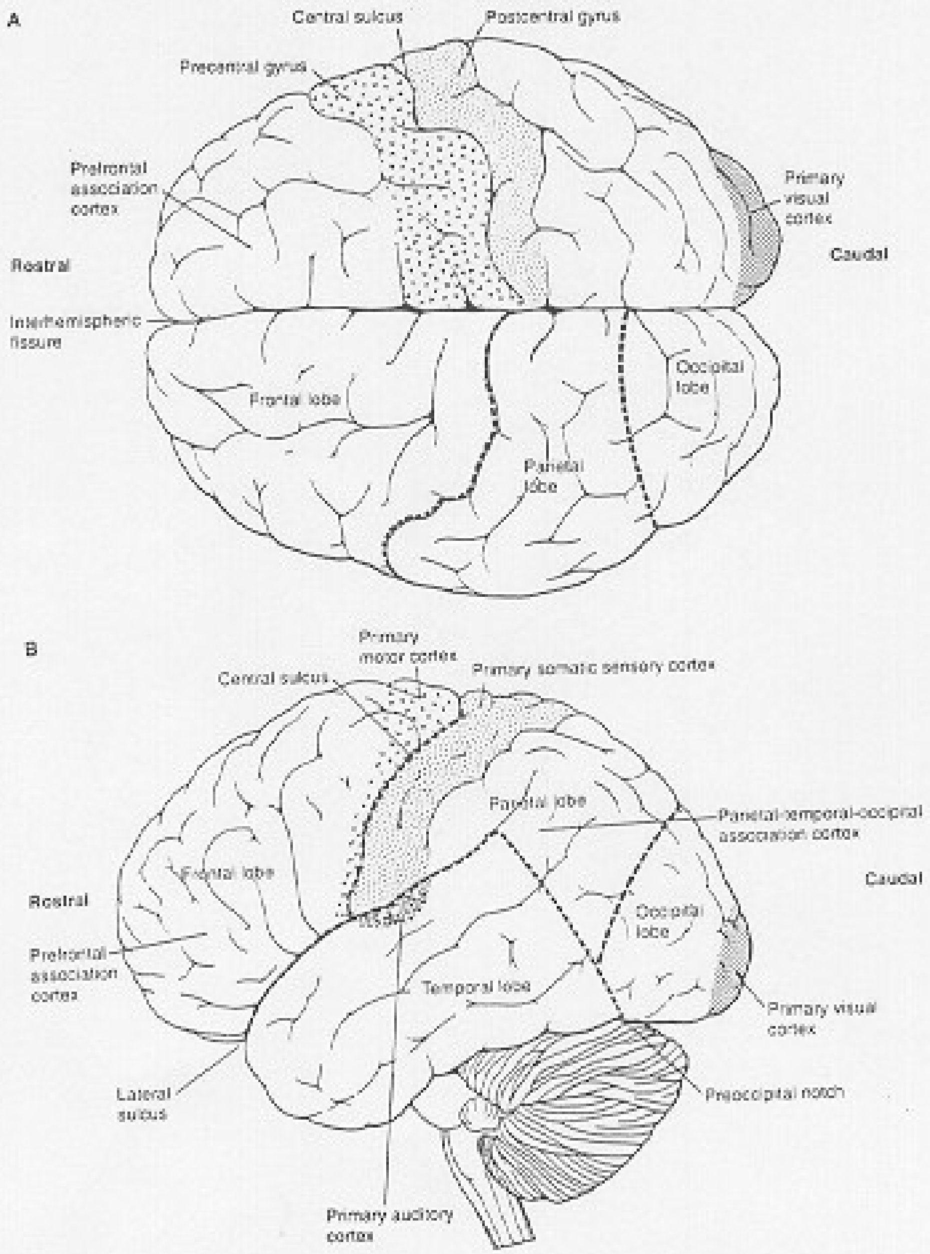

Figure 8: A contemporary abstract depiction of the gyral pattern. (Kandel at al 1991, p. 278)

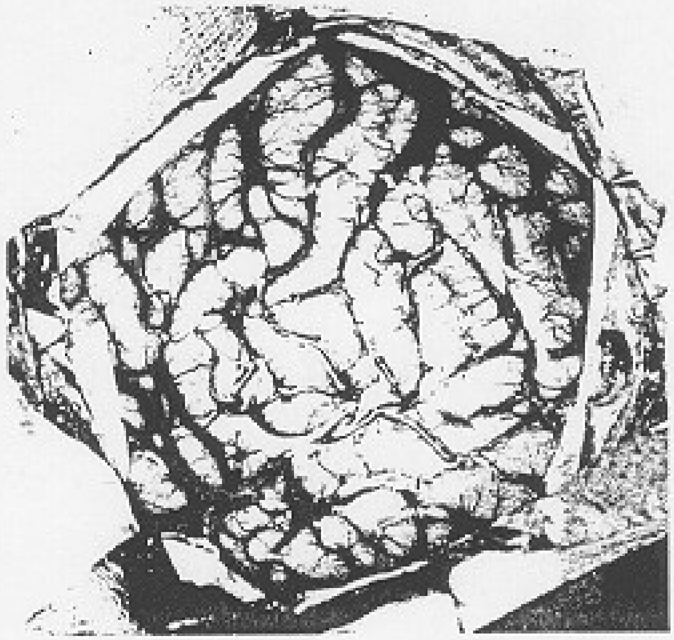

FIGURE 136

This shows the cerebral surface as seen during life through a craniotomy.[15] The bone-flap has been turned back and the dura mater opened to reveal the gyri, sulci and associated blood vessels. Many will agree that there is a faint resemblance to the abdominal contents of an animal with its tight-packed coils of ileum, which brings us back full circle to Erasistratus in the third century B.C.

A number of problems concerning the morphology of the cerebral convolutions still remain: their mode of production; the specificity of their arrangement in individuals, their phylogeny and function and, in particular, their possible correlation with intelligence.

It may well be that interest has lagged somewhat in this area of research as attention is more often focussed on more exciting and dynamic problems needing sophisticated machines and techniques for their elucidation.

Figure 9: A photograph of a living cortical surface showing the difficulty in recognizing the gyral pattern. (Clarke & Dewhurst 1996, p. 113)

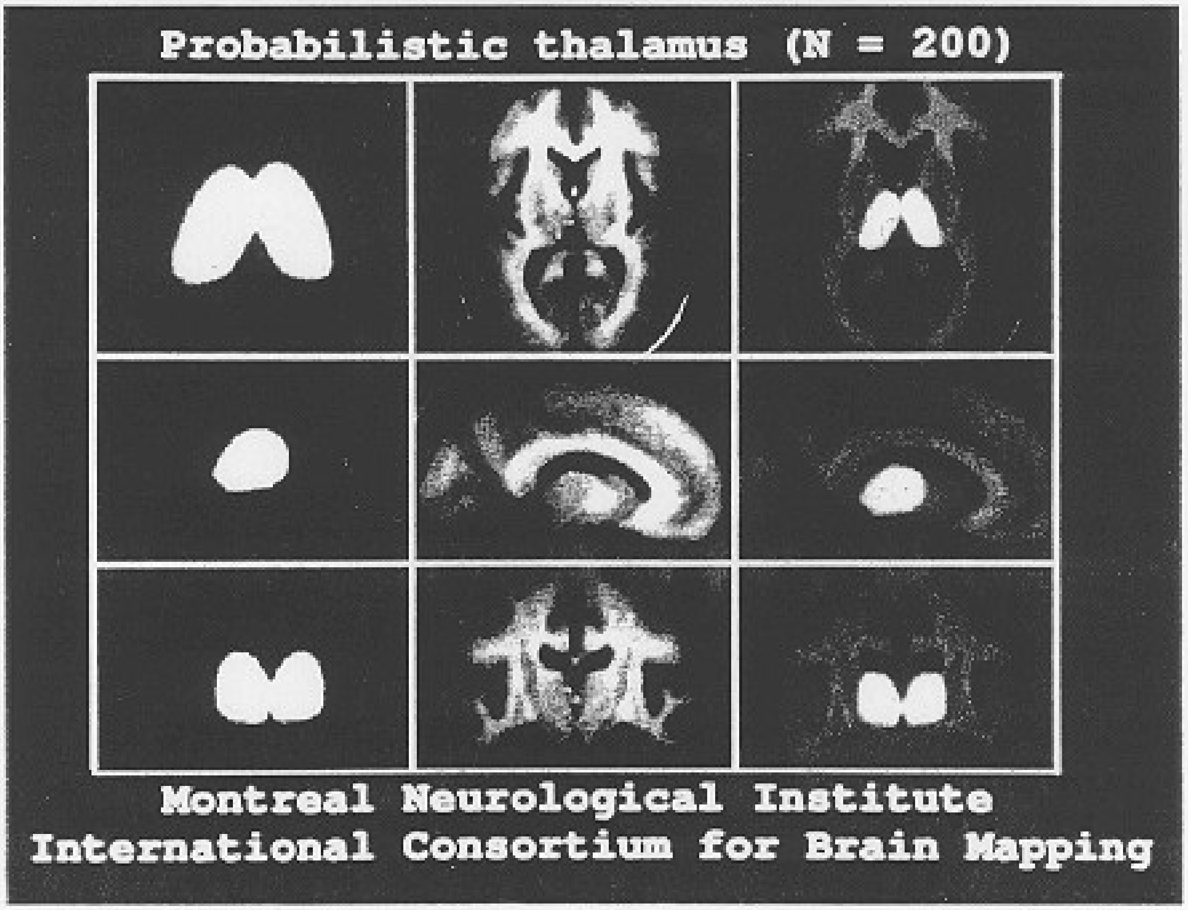

Figure 2 Triplanar views through a probabilistic map of the thalamus, derived by manual labeling of 200 brains from a 305 brain database. Each voxel value in the left image volume represents the likelihood of the voxel being in the thalamus. The central image volume is the same data as in Fig. 1 whereas the right column shows the superposition of the two volumes.

Figure *10*: A probabilistic map of the thalamus constructed by Evans' lab in Montreal. (Toga & Mazziotta 1996, p. 345)

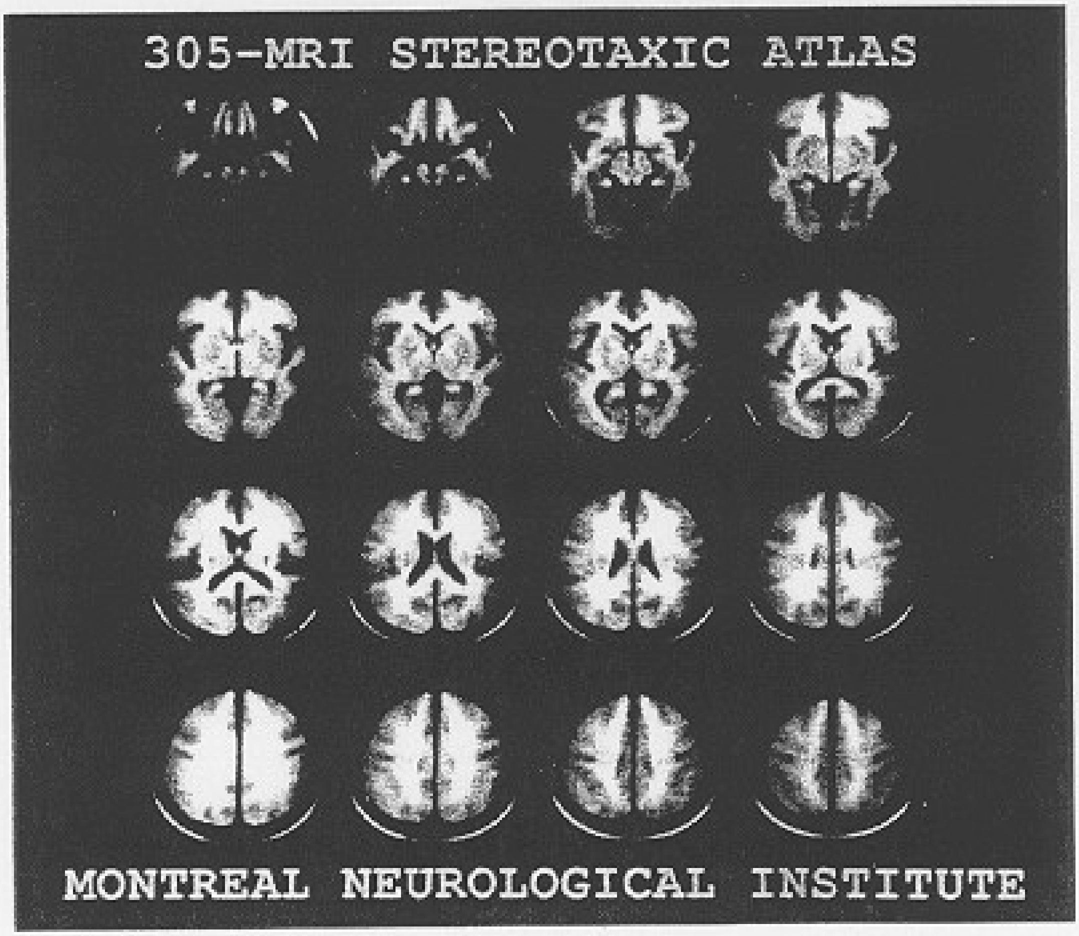

Figure 1 Mean MRI data set drawn from 305 young normal volunteers. The data set can be used as an anatomical atlas for locating functional activation data in Talairach space. It also provides a visual impression of local anatomical variability and an indication of how well a particular functional measurement can be localized.

Figure 11: Average images of brain slices from Evans' laboratory in Montreal.
(Toga & Mazziotta 1996, p. 344)

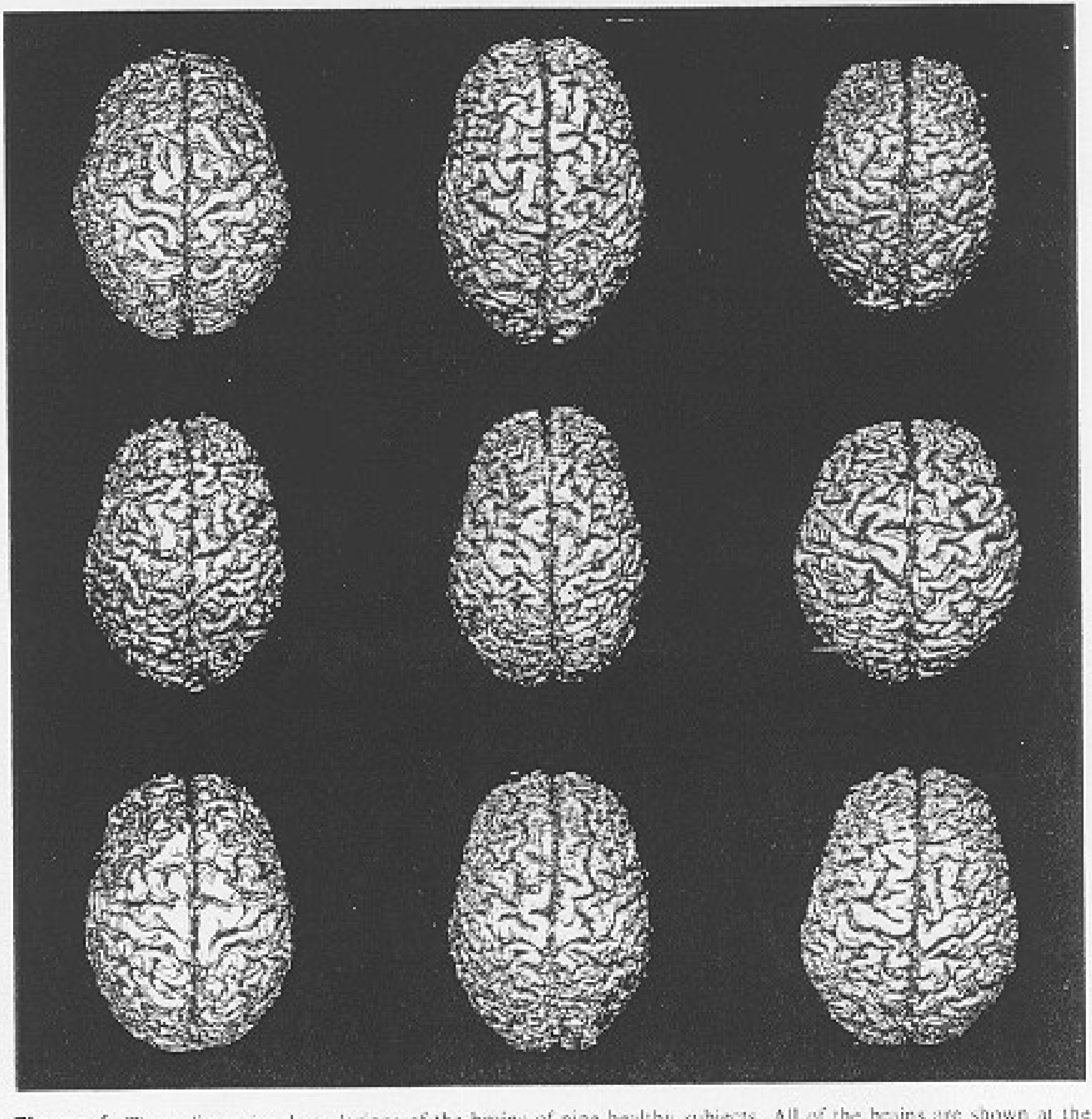

Figure 6 Three-dimensional renderings of the brains of nine healthy subjects. All of the brains are shown at the same scale and from the same orientation. Three of the subjects were female and six were male. Two subjects were black, one was Hispanic, and the other six were Caucasian. All subjects were right handed. Note the marked variability in brain size and shape.

Figure 12: 3-D renderings of MRI images of the cortical surface of different brains. (Toga & Mazziotta 1996, p. 332)

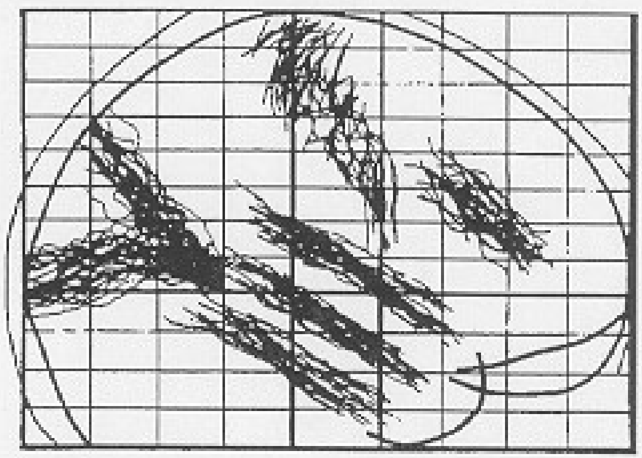

Figure 8 Residual intersubject variability after Talairach transformation. The images shown here are modified from the 1967 Talairach atlas and were mapped into "Talairach space" using the approach originally described by Talairach *et al.* The landmarks shown are the occipital sulcus, the parietooccipital sulcus, the central sulcus, the inferior frontal sulcus, and the superior, middle, and inferior temporal sulci. Compare the amount of residual variability to the sizes of the functional areas shown for the macaque brain in Fig. 1.

Figure 13: Drawing representing the variability in location of sulci among many different brains. (Toga & Mazziotta 1996, p. 334)