The Development of Neurophysiology

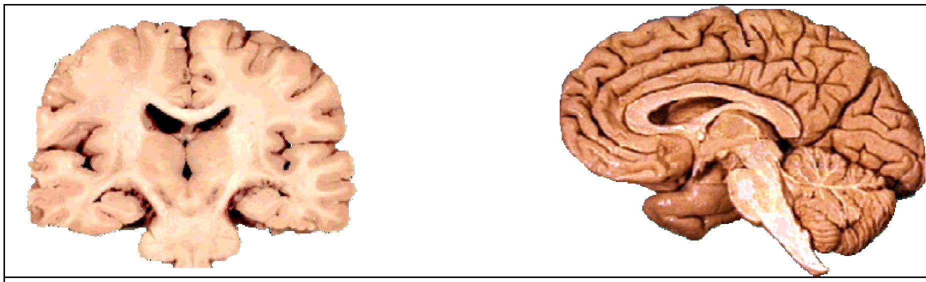
We next turn to physiology. Though physiology is not on our list of core disciplines in cognitive science, it has a special significance in the development of both psychology and neuroscience. Psychology has two parent disciplines; Philosophy and Physiology. Philosophy introduces the “big questions” about the nature and operations of the mind. Physiology--particularly the early physiology of the nervous system--marks the beginnings, not only of neuroscience, but also of the introduction of experimental methodology to the study of the mind.

The early development of physiology involves the development of an accurate knowledge of the gross anatomical structures of the body, and improved understanding of the functions of anatomical structures, and the development of an experimental methodology for testing functional hypotheses. From that point, neurophysiology and eventually neuroscience are fueled primarily by increasing the repertoire methodologies, both for visualizing ever finer structures and for experimentation to determine the functions of newly visualized structures.

As we’ll see, knowledge of even the gross anatomical structures of the nervous system and their function eludes theorists throughout most of history. This ignorance has two sources. First, prohibitions and/or stigma around dissection of human corpses create a lack of empirical investigation and documentation as to the gross anatomical structures. Second, a lack of valid empirical experimental methodology provides for very limited understanding of the corresponding functions and functional organization of gross anatomical structures.

Aristotle (384-322 BCE) performs dissections of animals to gain anatomical knowledge. His anatomical studies lead him to view the brain primarily as a radiator for the heart which generates sensations and emotions in 335 B.C.E.. In *Parts of Animals*[1] Aristotle claims that “...the brain cannot be the cause of any of the sensations, seeing that it is itself as utterly without feeling as any one of the excretions.” (Part 10, ¶2)

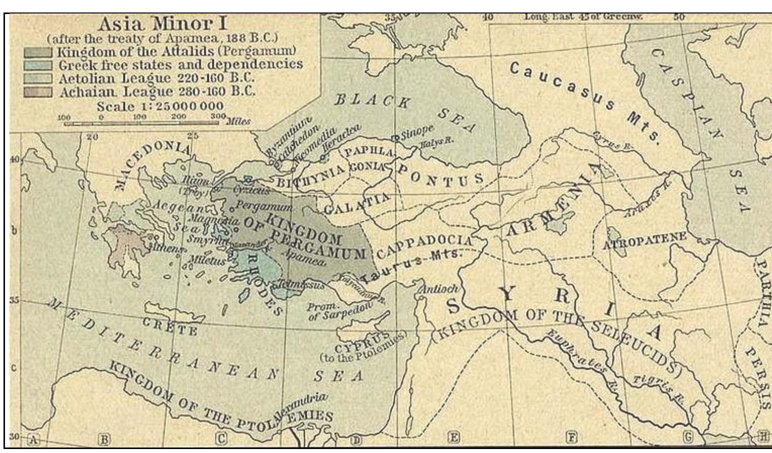
	
Aristotle (384-322 BCE)	



Human ventricles of the brain are a system of four structures continuous with the central canal of spinal cord. They are shown in mid-sagittal plane (middle) picture of the right hemisphere (upper left), and (upper right) coronal plane (vertical plane dividing the brain into anterior [front] and posterior [back])

While the Greek physicians Herophilus of Chalcedon (335-280 BCE) and Erasistratus of Chios (304-250 BC) perform relatively systematic human dissections around 300 BCE. Even in the enlightened Greek culture, the practice is stigmatized and in many places illegal. However, in the third century BC under Ptolemy I and his successor, Ptolemy II Philadelphus, the city founded by Alexander of Macedonia, Alexandria, develops a relatively unique social, cultural, political and intellectual climate which allows Herophilus and Erasistratus the freedom to dissect human bodies. Both before and after the period of Hellanistic Alexandria physicians looked for the most part to the dissection of animals to gain knowledge of the human anatomy.

Herophilus suggests that the ventricles are seat of mentality. It isn't until the Roman physician Galen of Pergamum delivers a series of lectures in 177 ADE that any anatomist considers brain itself as the seat of mentality. Galen (Claudius Galenus 129-200ADE), begins his career as Roman physician in his home town of of Pergamum, a Greek city, like Miletus, in Asia Minor. Pergamum is one of the greatest cultural and academic cities of its time, second only to Alexandria where Galen also studied medicine.



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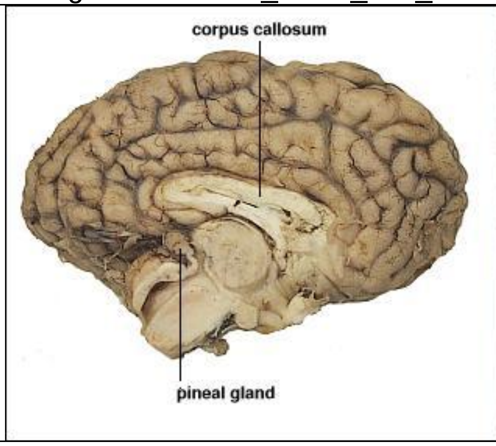
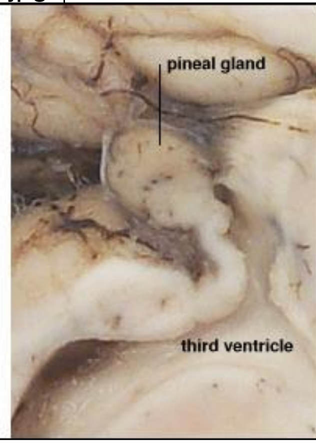
<tr><td>Pergamum circa 188BC
http://en.wikipedia.org/wiki/File:Asia_Minor_188_BCE.jpg</td><td>(Claudius Galenus 129-200AD)</td></tr>
<tr><td colspan="2">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<tr><td colspan="2">Pineal Gland
http://www.vivo.colostate.edu/hbooks/pathphys/endocrine/otherendo/pineal.html</td></tr>
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Scholars often describe Galen as the greatest medical researcher of the Roman period. He makes significant contributions to medicine, anatomy, physiology, logic and philosophy that shape thought in these areas for centuries. Roman law forbids dissection and autopsy of the human body, so Galen, like all physicians of the times is unable learn from human cadavers. Instead, he dissects the Barbary Macaque and other primates, transferring what he learns on the assumption that the anatomies are basically the same. However, Galen does have an advantage that most anatomists do not. As a physician to gladiators, Galen has many occasions to view the internal organs of their bodies. In Galen's major anatomical work, *De Usu Partium Corporis Humani* (*On the Usefulness of the Parts of the Body* ca. 210 AD) as well as in a famous earlier lecture (177ADE) he describes the ventricles and pineal gland. He argues against the idea--apparently widely espoused at the time--that the ventricles are filled with "psychic pneuma," the airy or vaporous substance supposed to interact with both body and mind. Galen also argues against the idea that the movements of the pineal gland act to regulate the flow of these pneuma within the ventricles. No one really listens, and such theories continue to dominate thinking throughout the middle ages.

The first anatomy textbook published in Europe is *Anothomia* written by the Italian physician Mondino de'Luzzi (ca. 1265-1326). Though de'Luzzi completes the text in 1316 while at the University of Bologna, it is not published until after his death in 1478 at Padua. The work is based upon de'Luzzi's own dissections, though most of the errors in Galen are repeated. Between the 13th and 15th century dissection increasingly becomes accepted at universities throughout Europe, together with an increasing interest in, and knowledge of anatomy. Interest in the brain remains centered upon the ventricles. Leonardo da Vinci (1452-1519) creates a cast of the human ventricles in

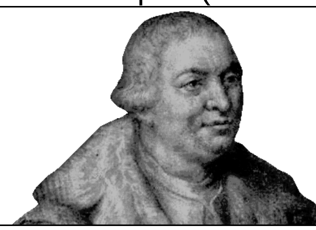
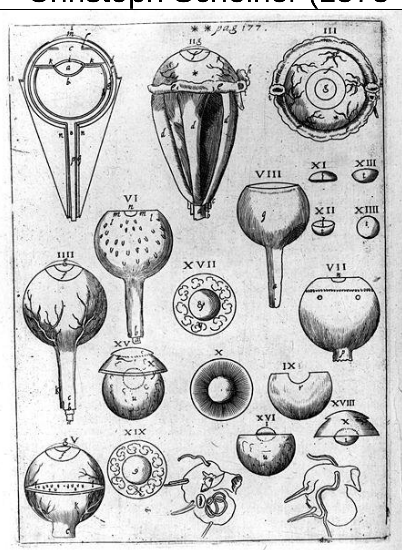
1504. In 1536 the italian Niccolò Massa (1485–1569) argues that the ventricles are filled with fluid (liquor cerebro-spinalis). Andreas Vesalius (1514-1564), a Belgian physician/anatomist publishes the next major anatomical work. Vesalius' seven volume *De Humani Corporis Fabrica* (On the Workings of the Human Body) in 1543. In the volume, *Libri septem*, of *Fabrica*, Vesalius argues against all ventral localizations and all theories that the pineal and other structures regulate the flow of animal spirits.

	
Leonardo da Vinci (1452-1519)	Andreas Vesalius (1514-1564)

Images from Vesalius' De Humani Corporis Fabrica
http://vesalius.northwestern.edu/flash.html

Vesalius' work represents a dramatic improvement upon previous anatomical knowledge, and corrects many of the mistakes in Galen. Throughout the remainder of the 15th century anatomists continue to improve their knowledge of anatomical detail. In 1550 Bartolomeo Eustachio (1514-1574), an Italian contemporary of Vesalius, traces the optic nerves to their origins in the brain. Gabriele Falloppio's *Observationes Anatomicae* (1561) includes a description of some of the cranial nerves. Giulio Cesare Aranzi (1529-1589) coins the term hippocampus in his *De Humano Foetu Opusculum* (1564). Girolamo Mercuriali (1530-1606) writes *De Nervis Opticis* in 1573 which further documents optic nerve anatomy.

Aranzi also stands out in the development of experimental methodology. His *Observationes Anatomicae* (1587) introduces the results of his experimental work on anatomical function, including his demonstration that the retina has a reversed image. Other contributions to a functional understanding of the nervous system include a work on neurological disease by Jason Pratensis (1486-1558) called *De Cerebri Morbis* (1549). Vesalius, who is working as a private physician at the time, publishes *Hydrocephalus ex vacuo* (1550), which provides an accurate account of hydrocephalus (a build-up of fluid inside the skull, leading to brain swelling).

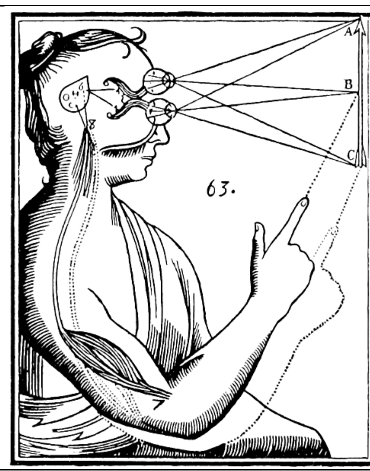
	
Girolamo Mercuriali (1530-1606)	Johannes Kepler (1571-1630)
	
Christoph Scheiner (1573-1650)	Jason Pratensis (1486-1558)
	A plate (left) from Kelper's *Ad Vitellionem paralipomena, quibus Astronomiae pars optica traditur* depicting the structure of the eye. From http://en.wikipedia.org/wiki/File:Kepler_Optica.jpg

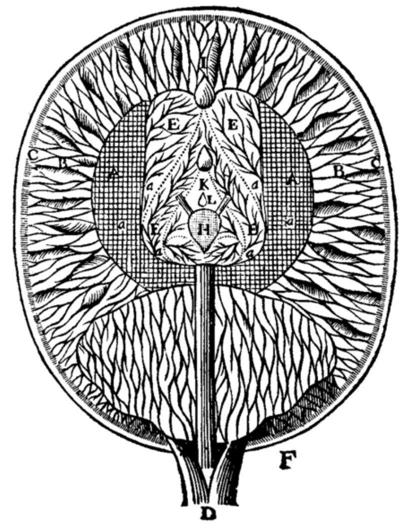
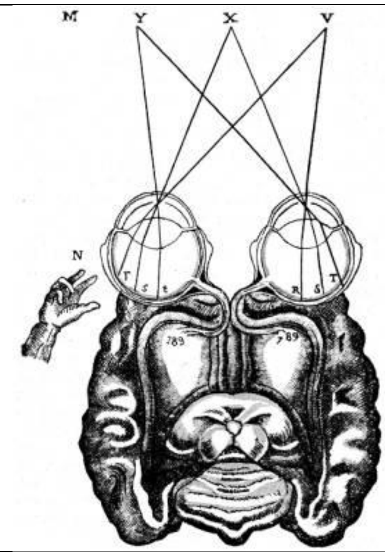
The 16th century sees a number of contributions to physiology from astronomers. In 1604 Johannes Kelper (1571-1630) publishes *Ad Vitellionem Paralipomena, Quibus Astronomiae pars Optica Traditur* or *Supplements to Witelo, on the Optical Part of Astronomy*. The *Supplements* includes a discussion of the anatomy of the eye and the first explanation of the optics of the eye. Kepler's *Dioptrice* (1611), an account of the properties of lenses, includes the first explanation of the optics of myopia, as well as a statement of the projection theory of stereoscopic vision.

Christoph Scheiner (1573-1650) another German astronomer publishes *Oculus, hoc est: Fundamentum opticum* (1619). *Oculus* makes several notable contributions. Scheiner provides the first demonstration that accommodation is an active process. He likewise identifies the retina as the organ of vision. He is the first to use fixatives to preserve the eye for anatomical study, which allows him to create the first accurate diagrams of the human eye. He also discovers the near pupil reflex.

Accommodation is a reflexive action by the eye allowing a person to switch their gaze between objects at different distances. In order, for example, to switch from viewing a nearby object to viewing a distant object the eye must adjust the shape of its lens, alter its pupil size (near pupil reflex), and coordinate its movements with the other eye so as to maintain the position of the object in the center of the retinas of each eye. The coordinated movement of the eyes is called vergence, and it makes binocular depth perception possible.

Scheiner publishes *Rosae Ursinae Sive Solis.* in 1626-1630. Though these volumes primary concern Scheiner's observations of the sun, they also include the first direct observation of the retinal image.

	 
René Descartes (1596-1650)	Descartes' diagrams depicting the pineal gland facilitating visual-motor function (left) and the communication of pain (right) in *Meditations Métaphysiques*

	
A diagrammatic section of human brain from René Descartes' *Treatise on Man*	Descartes' diagram depicting visual processing from *La Dioptrique*

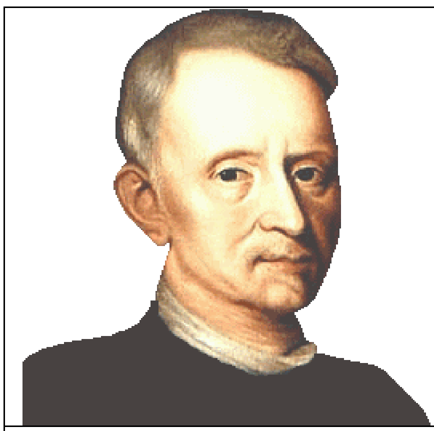
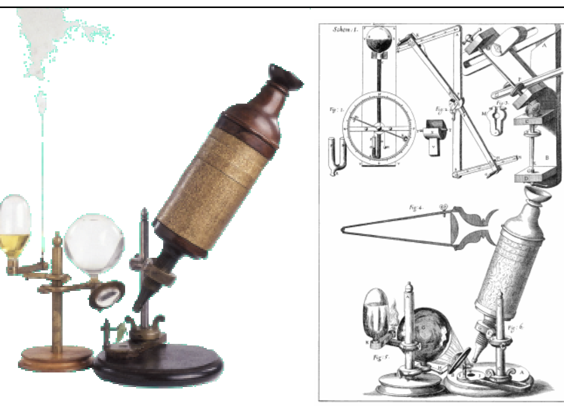
In 1637 René Descartes publishes *La Dioptrique* as one of three appendices to his *Discourse on Method*, each offered as an illustration of Descartes' method. *Dioptrique* is a treatise on optics. Though not particularly original in its results from optics, it articulates the corpuscular theory of light and suggests for the first time that the retina projects directly onto brain (in his view, onto the walls of the ventricles).

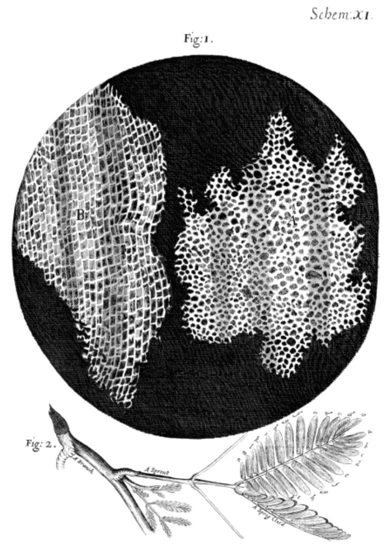
Though a dualist, Descartes makes some of the first steps towards psychology and neuroscience. Descartes maintains a very strong long-term interest the workings of the physical body, and spends a great deal of time dissecting cadavers. His theory of mind-body interaction is based upon my knowledge of gross neuroanatomy. Specifically, (1) Descartes posits the pineal gland as the "seat" of mind-body interaction. He hypothesizes, contra Galen, that the pineal gland plays a role in sensation, imagination, memory and the causation of bodily movements as early as my first work, *Treatise of Man* (written 1637, published 1662). Thus, the pineal gland serves as the principle organ for sensus communis--the communication between the body and the soul. Both the soul and the body's animal spirits can affect the pineal gland by literally moving it, thereby allowing each to act on the other. Additionally, (2) Descartes adopts Galen's hypothesis that the nerves are hollow tubes that contain[2] "…a certain very subtle wind, or rather a very lively and pure flame, which is called 'animal spirits'." (p.19)

Descartes' view proves important, in part because it becomes very influential. It is also based on physiology--though he am mistaken on numerous points regarding the pineal gland, etc.. Finally, Descartes views the body as a machine capable of autonomous action--thereby indirectly furthering physical explanations of the mind. Indeed, he notes that,[2]

> …it is not necessary to conceive of this machine as having any vegetative or sensitive soul or other principle of movement and life, apart from its blood and its spirits, which are agitated by the heat of the fire burning continuously in its heart—a fire which has the same nature as all the fires that occur in inanimate bodies. (p.113)

We'll end this section with a final contribution from optics. Robert Hooke (1635-1703) is a somewhat obscure English "natural philosopher" and a polymath. Nevertheless, he proves remarkably influential in the sciences, through both his experimental and his theoretical contributions. Hooke's Law, which describes the tendency of elastic materials to deform under stress, probably stands out as Hooke's best-known scientific contribution. However, from the perspective of cognitive science, Hooke's legacy derives from his position as the "Father of Microscopy."

	
Robert Hooke (1635-1703)	Hooke's microscope and his diagram of it from *Micrographia*

	
Hooke's drawing of cork cells from *Micrographia*	

Hooke publishes [*Micrographia*]() in 1665. The book contains a record of Hooke's observations using a microscope (of his own devising). Hooke's observations of cork, specifically, the presence of cells (see drawing), prove the most significant from the standpoint of cognitive science. One cannot underestimate the existence of visualizable cells, in the development of biology and neurobiology. Hooke himself, however, did not observe cells in animals, and did not believe that animals were composed of cells.[3]

> First, in that it had a very little solid substance, in comparison of the empty cavity that was contain'd between, as does more appear by the Figure A and B of the XI. *Scheme*, for the *Interstitia*, or walls (as I may so call them) or partitions of those pores were neer as thin in proportion to their pores, as those thin films of Wax in a Honey-comb (which enclose and constitute the *sexangular celts*) are to theirs.
>
> Next, in that these pores, or cells, were not very deep, but consisted of a great many little Boxes, separated out of one continued long pore, by certain *Diaphragms*, as is visible by the Figure B, which represents a sight of those pores split the long-ways. (p.113)

Ending the discussion of physiology here is somewhat arbitrary. Few historians suggest a specific time for the beginning of neuroscience. However, we will return to the scientific study of the brain when we discuss neuroscience. The discussion in this section focuses upon the development of gross anatomical and neuroanatomical knowledge, the introduction of experimental techniques and devices in physiology, and the early attempts at identification of the function of gross neuroanatomical structures.

These three developments eventually allow theorists to begin to systematically study the nervous system at the many levels of functioning that characterize neuroscience.

Sources

1. Aristotle. On the Parts of Animals (MIT Internet Classics Archive, 350 BCE).
2. Descartes, R. Traite de l'homme (Treatise on Man) (ed. Hall, T.S.) (Prometheus Books, Amherst. NY, 2003).
3. Hooke, R. Micrographia: or, Some physiological descriptions of minute bodies made by magnifying glasses (J. Martyn and J. Allestry, London, 1665).