Artistic and Intellectual Factors in Scientific Discovery: Ocular Anatomical Drawings

Marc DE MEY

Although they appear opposed to each other in many ways, science and religion share a common mistrust with regard to images. Church buildings and museums might seem in contradiction with this. Early patriarch warnings have not been able to suppress the production of a wealth in paintings and statues, if not as representations of religious truth then certainly as expressions of reverence for it. Many scientific instruments too are aimed at imaging in intricate ways and produce pictures that are shown with similar reverence in scientific publications as achievements of science. Apparently, distrust of the image does not have to entail its denial. The image is accepted and eagerly used as a powerful instrument if it is seen to express a truth that can be cast in the apictorial symbols of language or mathematics.

The word is superior to the image. One picture can be worth a thousand words, but without words reflecting the idea behind it, a picture has no meaning! Therefore the pictorial mode of representation has been regarded as a powerful servant for promoting and extending established doctrine but not as a means for discovery nor as the ultimate carrier of accepted truth. The ultimate medium for expressing the content of science or religious doctrine is the system of arbitrary symbols provided by language. In the beginning is the word. Then pictures may help spreading it.

A top-down view of the rendering of observation is supported by some current science studies (see *Representation in Scientific Practice* edited by M. Lynch and S. Woolgar, 1990, especially Amann & Knorr's "The fixation of (visual) evidence") but it is also found in Ludwik Fleck's (1935) book that was so instrumental to Kuhn's (1962) monograph.

In an apparently cognitivist statement, Ludwik Fleck claims that "there is no visual perception except by ideovision and there is no other kind of illustration than by ideograms" (Fleck, 1979, p 141, originally in German, 1935). This looks like a straightforward cognitive point of view which reduces perception entirely to top down interpretation of data. The ruling worldview or paradigm which generates much of the environment in terms of expectations needs only a few anchorpoints in ambiguous data to assure its connection with the world. Perception is from the inside out, with the ideas of the mind as forces that give a specific shape to a set of multiform data.

Fleck finds inspiration and support for this idea in a number of anatomic drawings, including a representation of the eye from 1539, reproduced from Sudhoff

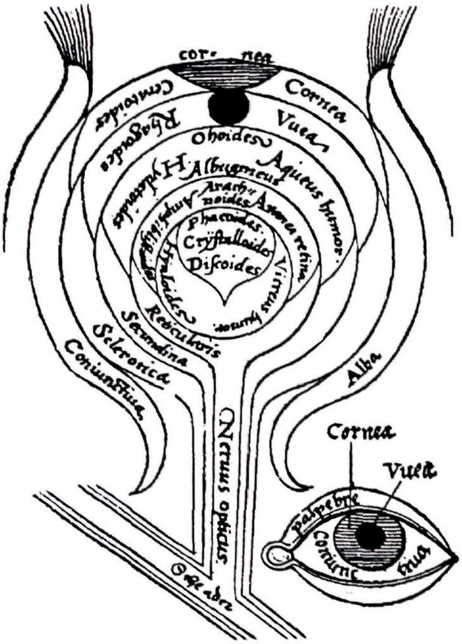


Fig. 1 – Diagram of the eye in 1539 publication printed in Strassburg, from Sudhoff 1907, p 24.

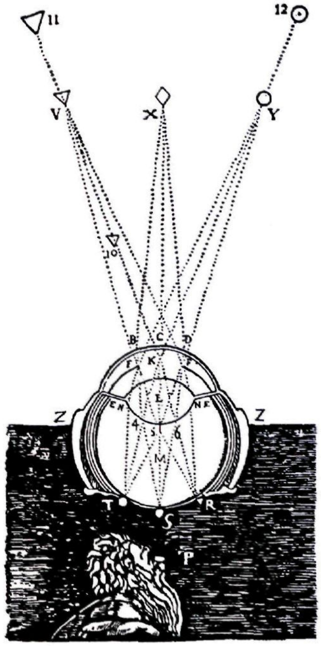


Fig. 2 – Diagram of the eye from Descartes (1637)

(1907). It is the anatomical drawing of the eye in a later edition of the *Margarita Philosophica*, an encyclopedic work by Reisch that was first published in, or around, 1499. The drawing differs on essential points from modern schemes expressing the fundamental divergence between the medieval theory of ocular functioning and the modern view that originated with Kepler in 1604. This modern view is represented in a picture repeatedly used by Descartes in his *Dioptrique* of 1637.

In his own publication of 1604, Kepler uses a representation of the eye borrowed from a publication by Platter in 1583. Indeed, in the one hundred year period between our two pictures, many anatomical drawings of the eye were published. And decades before Kepler's theoretical innovation, the medieval representation had been changed by several anatomists in such a way that around 1583 the dominant picture of the eye had become almost correct! This seems to contradict Fleck's claim. Here perception seems to change while the ideas lag behind. This is incompatible with an ideogrammatic view of pictures. Why would, within an ideogrammatic frame, the picture be changed if the idea remains the same? How can a pictorial representation come ahead of the conceptual scheme by which it will be explained?

The evolution of pictorial representations of the eye in the second half of the sixteenth century suggests a more complicated relationship between theory and data than the one way dependency which Fleck claims. Possibly, his notion of *Denkstil* is not the most appropriate unit of analysis to trace such developments, though it might explain part of the story. As an exercise in the cognitive analysis of a discovery, we will take a closer look at this episode in which the anatomical diagram precedes the theory. After a sketch of the situation in anatomy at the beginning of the sixteenth century we will explore the content and the scope of a notion of style and then introduce additional historical data to indicate that more refined analysis is needed and possibly better cognitive theory to explain the changing picture.

1. THE PERSPECTIVIST PARADIGM

The two anatomical representations of the eye belong to different paradigms. The picture based upon Reisch is part of a centuries old tradition that views the crystalline lens as the central organ within the eye that intercepts incoming rays so as to form a reduced but upright image of the visual field. The picture promoted by Descartes illustrates the concept of the retinal image. It acknowledges refraction and focusing by the lens to account for an inverted image on the concave retina.

The difference between the two paradigms can be compared to the difference between the Ptolemaic and the Copernican model in astronomy. Both express a fully developed view on the functioning of the visual system and the hold of the first view upon the mind of specialists is such that moving to the second one turns out to be extremely difficult.

We will label the first view the *perspectivist paradigm* because it corresponds to the concepts and images behind the familiar frame of perspective drawing as developed by Renaissance artists. In fact, linear perspective drawing is a relatively late application of that theory of visual perception of which the basic concepts were developed around the year 1000 by the Arabic scholar Alhazen (Al-Haytham in Arabic).

The second view should be called the *retinal image paradigm* and is really Kepler's discovery although he modestly presented it as some (minor) modification of the earlier paradigm (Kepler, 1604). Lindberg (1976) and Straker (1981) debate whether it is indeed a paradigm shift or an internal development.

1.1 The ancient heritage: Euclid, Ptolemy and Galen

The perspectivist paradigm is an ingenious compromise between the opposing doctrines of extramission and intromission (see Lindberg 1976). Extramission understands vision as resulting from the emission of visual rays by an eye that is literally reaching out to visual objects in an active way. Intromission understands vision as resulting from the impact upon the eye of something traveling from the visual object to the viewer, such as light, or something of the object affecting the medium between the object and the viewer in a way that the viewer's eyes sense. While intromissionists can call to their support the easily observable fact of after-images, the extramissionists can fully deploy an impressive geometric apparatus around the rectilinear propagation of "sight" (the physical "ray of light" developed out of the psychological "visual ray"). An ambitious extramissionist theory of vision is Euclid's *Optics*. In origin, the Greek science of optics or

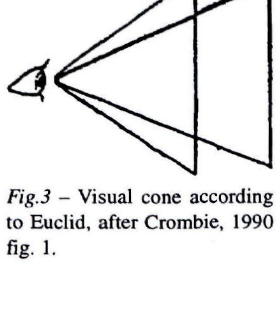


Fig.3 – Visual cone according to Euclid, after Crombie, 1990 fig. 1.

perspectiva (its translation in Latin) starts out as the science of visual perception. In his optics book (see Ver Eecke, 1938) organized in theorems in the same way as his famous books on geometry, Euclid introduces concepts like visual angle, perspective in the sense of a specific viewpoint and especially the notion of the visual cone. The viewer and his object are connected by a cone that has its apex in the eye of the viewer and its base in the perceived object.

This cone becomes the major unit of analysis and it even allows Euclid to handle some aspects of binocular vision. Almost five centuries later, in the second century, Ptolemy impressively expands the extramissionist mathematical model of visual perception, including a detailed analysis of binocular vision based upon first rate experimental data. Simon (1987) rightly wonders what would qualify as experimental psychology if Ptolemy's experiments would not. Ptolemy (whose preserved work in optics has recently become available in a French translation by Albert Lejeune, 1989) establishes the basic skeleton and much of the substance for further major works. He combines the visual cone with a central ray, the visual axis, and includes detailed discussions of seeing through mirrors under the heading of perceptual errors. Indeed, reflected visual rays make you see things at locations where they are not present.

In the same century, the pivotal physician Galen establishes a doctrine about the structure of the eye that will remain influential until the seventeenth century and beyond. He lists the major anatomical parts of the eye and attributes the pivotal role to the crystalline lens or central part receiving the visual information. His theory is not entirely compatible with the extramission views of the mathematicians Euclid and Ptolemy. His viewer is not emitting rays but he is active in sensitizing the medium and he registers some kind of feedback in the medium (the air).

With the visual cone and the central location and role of the crystalline lens, the major constituents of the perspectivist paradigm are already present in antiquity, but they are linked to an extramissionist approach. An Arab author will combine them in a successful way with an intromission viewpoint.

1.2 The Arab innovative integration

From the ninth century onward, during the great cultural expansion of the Arab realm, the science of vision of the ancient Greek heritage was studied thoroughly and in important ways expanded.

On the medical side Hunayn adopted Galen's model of the eye and from his work we have the first diagrams in a long series to follow. Notice, however, that while Hunayn lived in the ninth century, the first diagrams of the eye stem from copies of his work from the twelfth century (see Eastwood, 1982). Polyak (1941, p 107) notices an ambiguity in the transmission of Hunayn's description of the eye. While the crystalline lens is correctly described as flat, it is depicted as a circular sphere.

Through Hunayn, who according to Eastwood even emphasizes more than Galen the centrality of the lens, our late-medieval authors will learn about Galen.

With respect to the analysis of perception itself, the major combination of the cone model with intromission comes after a subtle but important modification of the extramission position.

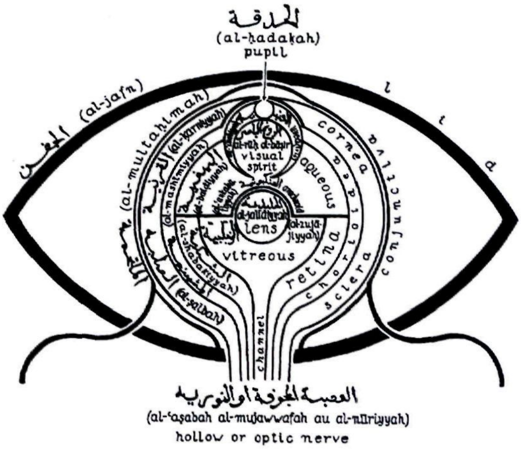


Fig. 4 – Eye diagram illustrating Hunayn's theory of vision, from Polyak, 1941, fig. 7.

Many issues with respect to the optics of vision come down to understanding, not about one single visual cone, but about sorting out several kinds of cones. As an early Arab investigator of vision, Alkindi accepts the extramission point of view after thorough analysis, including some optical experiments. Based upon these experiments, he comes to the important principle that a source of rays, whether visual rays or light rays, emits these rays from every point of its surface. This also applies to common objects reflecting light. From every point they radiate it back in every direction.

Alkindi's experiments are quite simple. They deal with one light source shining through several holes in a screen and projecting patches of light on a second screen behind it or with two or three sources (candles) shining through one hole. By extinguishing a candle and by covering a hole one can demonstrate how light behaves according to the principle stated above. In the three candle situation, these objects can be considered representative points on a continuous source and in that case the reversal of the projected "image" is easy to understand.

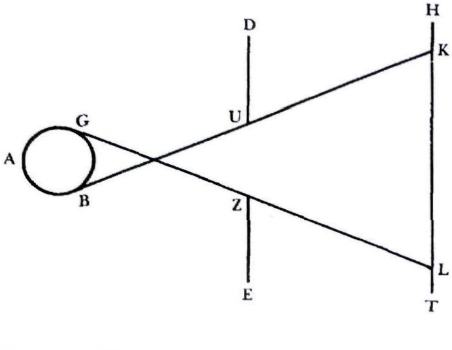


Fig. 5 – Alkindi type experiments on ray tracing, from Lindberg, 1976, fig. 2.

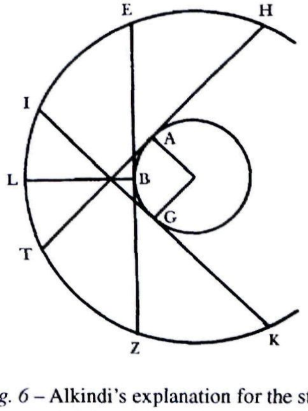


Fig. 6 – Alkindi's explanation for the strength of central vision, from Lindberg, 1976, fig. 4.

Alkindi used this principle to account for a fact that Ptolemy also had emphasized: we see best along the central axis of the visual cone and vision weakens towards the periphery of the visual field. Alkindi, however, saw the frontal surface of the eye as the source of visual rays rather than its center and considered each point of the cornea as radiating in all directions. In this way he could prove geometrically that the highest density of rays or the highest visual power is attained along the visual axis.

In a major treatise, inspired upon Ptolemy's *Optics* (see Smith, 1990), Alhazen managed to combine Alkindi's important optical principle with an intromission theory of visual perception. Alkindi's principle might seem to complicate the situation very drastically for an intromissionist. If every point emits or reflects light rays in all directions, every eye should be confronted with nothing but blurriness. But Alhazen had the ingenious idea of allowing only one kind of rays to penetrate into the eye: those that arrive perpendicularly on the cornea. This brilliant move preserves the visual cone but now with inbound rays rather than with outbound ones. The overwhelming multitude of oblique rays is supposed to be deflected and by that process to become so weakened that they do not contribute to any image. The perpendicular rays, to the contrary, enter the sphere of the cornea converging further within the eye until they impinge upon the crystalline lens. Since the crystalline body is slightly in front of the center of the eye, the rays are intercepted before they intersect and a reduced but upright image of the visual field is composed within that body. Alhazen envisages the possibility of rays further converging to a point and crossing but, since that would yield a reversed image, he rejects that line of thought as obviously contradicted by experience: we see the world upright!

At the back, the crystalline body connects with the optic nerve which is thought of as lying on the visual axis and which makes the connection with the mental powers. From the lens on to the brain and within the brain, perception obeys principles of spiritual movement and analysis and is no longer the pure product of rectilinear transmission of rays. In a sense, one can think of genuine perception as starting in the lens and achieving completion in the inner senses. A major combination of the images of the two eyes is supposed to happen at the optic chiasma. An integrated interpretation of the perceived object is than further achieved at the common sense (sensus communis) which, later on, will be located in the frontal part of the brain (the first ventricles).

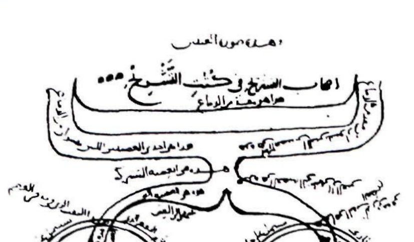
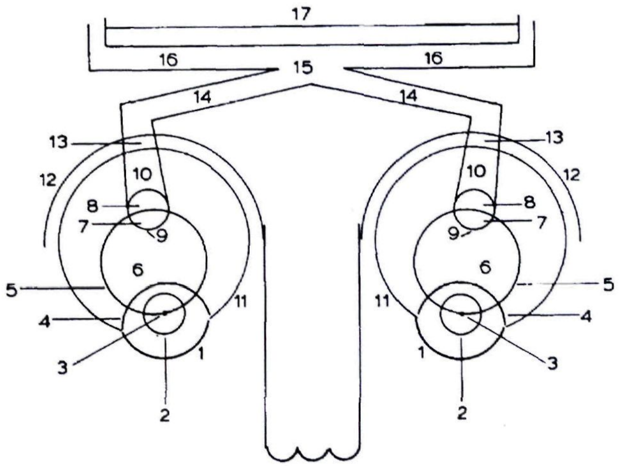


Fig. 7 – Pictorial representation of the two eyes in Alhazen manuscript of 1083 (Fatih 3212), from Sabra, 1989, vol. 2, plate 1.

One of the oldest schemes depicting the eyes stems from a copy of Alhazen's *Optics* in which he developed his model. It is probably made by his son in law who also made a copy of the text. The picture



1. Lower eyelid.
2. Cornea.
3. Uveal aperture (pupil).
4. Upper eyelid.
5. Uveal sphere.
6. Albugineous humour.
7. Crystalline humour.
8. Vitreous humour.
9. Web-like membrane (arachnoid), encircling the crystalline–vitreous body.
10. Conically shaped nerve.
11. Conjunctival sphere, containing the eyeball.
12. Concave bone in which the eye is set (orbit).
13. Aperture in the concave bone.
14. Nerve attached to one of the eyes.
15. Common nerve (optic chiasma).
16. Optic nerve originating from the brain.
17. Front of the brain.

Fig. 8 – Schematic representation of the picture in Alhazen manuscript, from Sabra, 1989, vol. 1, p. 63.

(see figure 7) shown is from Sabra's recent translation with introduction and extensive comments on Alhazen's text (Sabra, 1989, vol 2, plate 1).

In the translation, Sabra (1989, vol 1, p 63) provides the following scheme and table of terms to explain the diagram (see figure 8). Apparently, there should have been a whole tradition in the Arab literature for depicting such eyes-nose-brain configurations since they return, sometimes more technically developed as in Alfarisi's (Kamal al-Din) comments of two centuries later where stereoscopic vision is included (see figure 9) along clearly Ptolemaic lines (for comparison with Ptolemy, see the edition of his Optics by Lejeune, 1989, with commentaries and French translation).

Some Western manuscripts from the same period contain similar but more primitive schemes. Sometimes they are so highly stylized that the bodily parts are barely recognizable. Murdoch (1984, p. 327) reproduces a thirteenth century diagram, intermixed with text, on which an irregular shape between two sets of concentric circles evokes, not without a hint, an interpretation in terms of a nose between two eyes. However, the large boomerang structure to which these entities are connected represents the symmetrical brain and the small triangular, rectangular and diamond shapes on it are ventricle locations corresponding to inner senses such as common sense, imagination, cognition and memory. A slightly easier version to decode is in a

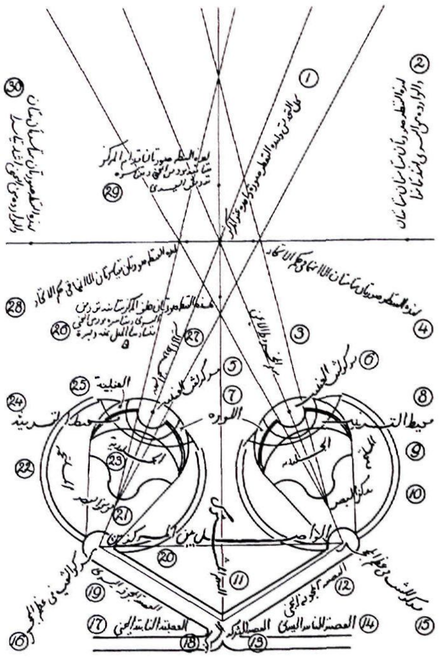


Fig. 9 – Diagram of the two eyes from a manuscript of Kamal al-Din written in 1433, from Polyak, 1941, fig. 12.

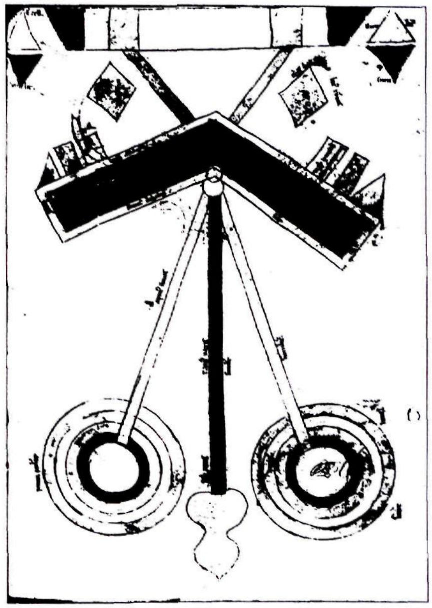


Fig. 10 – Drawing from 12th or 13th century of eyes, nose and brain, Cambridge, Gonville & Caius College Ms. 190/233, F. 6r, from Clarke & Dewhurst, 1975, fig. 59.

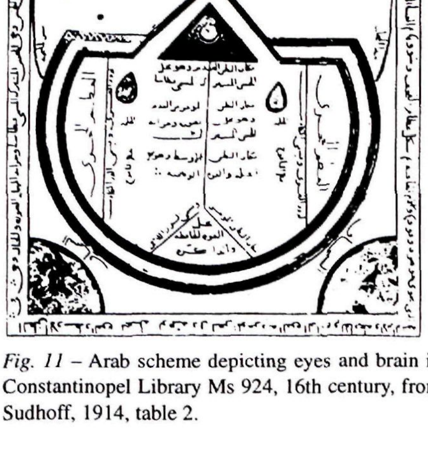


Fig. 11 – Arab scheme depicting eyes and brain in Constantinopel Library Ms 924, 16th century, from Sudhoff, 1914, table 2.

Cambridge manuscript: In an Arabic manuscript quoted by Sudhoff (1914), we recognize two eyes linked to the brain through the optic chiasma. The text explains the segmentation of the brain around the ventricles (depicted as small oval shapes) in again four traditional powers or inner senses: sensus communis, imagination, judgment and memory.

Typically for most of these schemes is their geometrization. The eye as a whole and the component parts are perfect spheres or segments thereof. This is not entirely due to matters of style. Alhazen's selection criterion for rays contributing to perception is a geometrical one. Penetration of perpendicular rays makes sense only for perfect geometric bodies. And for the criterion to apply all the way through the crystalline lens, all transparent layers of the eye have to have a curvature that allows for concentric organization behind the cornea. Geometrization is thus also part of the theory. How well this is understood is apparent from the fact that it is maintained in late medieval Western schemes which adopt the Arab views.

1.3 The late-medieval expansion and solidification

Optics or the science of perspective becomes a pivotal discipline in late-medieval intellectual development. Light is seen as an element common to the heavenly realm of God and mortal life on earth providing a link between spiritual and material reality. Vision is the prototypical process of cognition and the analysis of visual perception a central issue in the study of knowledge and belief. The Arab elaboration of ancient doctrine on vision is eagerly taken over and linked with theological issues.

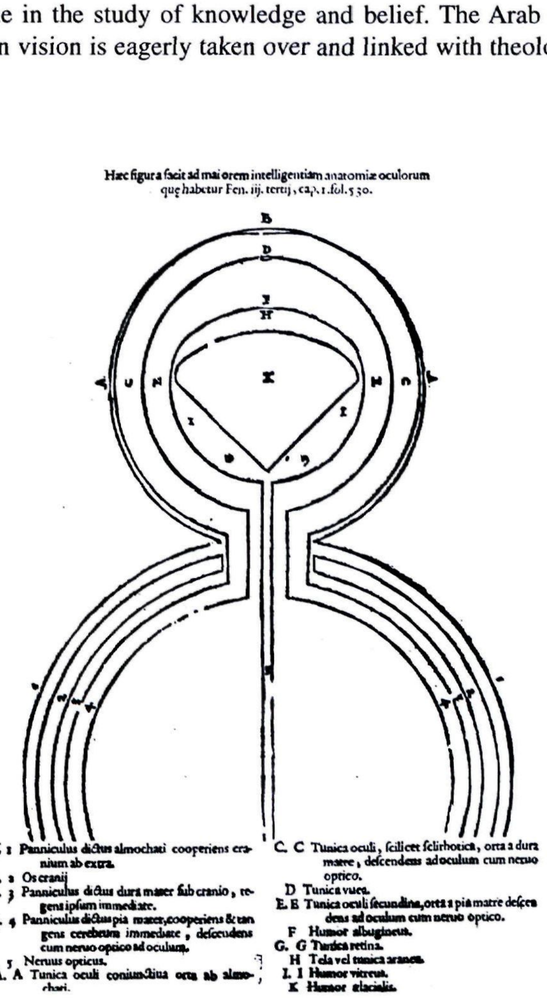


Fig. 12 – Schematic representation of eye and brain in printed version of Avicenna's medical Canon, first edition 1544, from Ghent university library.

An integrated theory of cognition connecting the classical senses to a set of internal senses had been worked out by the Arab scholar Avicenna who had an immense influence on medicine and philosophy in Europe. A sixteenth century printed edition of his *Canon* still preserves the Arab styling in a remarkably restrained rendering of an eye-brain combination. Notice the size and the shape of the centrally located crystalline body.

Bednarski (1931) shows some pictures which indicate how the basic Arab scheme is followed in the West. One stems (see figure 13) from a copy of the *Perspectiva communis* of Pecham. A popular medieval textbook on vision (perspective) that circulated widely. It is from a manuscript of the Vienna Nationalbibliothek which is said to have originated around 1367 (Pecham's original text is from 1277-1279).

Two other drawings depict a kind of horizontal cut through the head to locate the structure and the connections of eyes and brain, listing again the internal senses. One, for which Bednarski provides no date, is from a manuscript preserved at the university of Basel (see figure 14). The third stems from the 1430 Czechel manuscript in the library of Krakau (see figure 15). The indications on the horizontal line again list the internal senses but the labels higher on read: perfectissima, perfectior, perfecta. This is in line with a view of perception as a gradual process of purification which is again in the tradition of Ptolemy and Alhazen and also of Aristotle. Gradually the perceptual features are reconverted in more and more abstract conceptual categories so that ultimately only a generic concept (a "universal") is withheld by the intellect. Avicenna's discussions of the inner senses have been very influential in the exploration of such post-ocular perceptual processes.

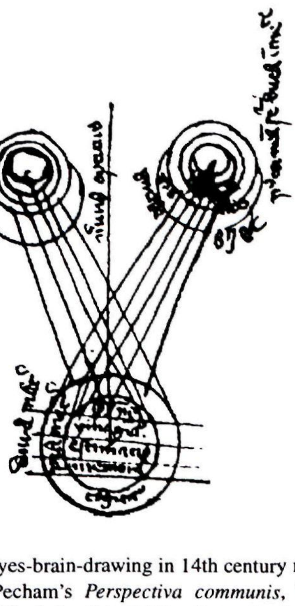


Fig. 13 – Eyes-brain-drawing in 14th century manuscript of Pecham's *Perspectiva communis*, Wien, Nationalbibliothek (Ms5210), from Bednarski, 1931, fig. 10.

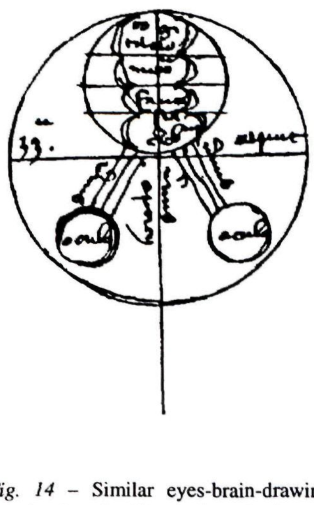


Fig. 14 – Similar eyes-brain-drawing, Basel university library, from Bednarski, 1931, fig. 6.

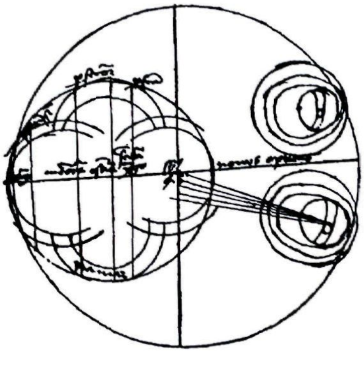


Fig. 15 – Eyes and inner senses in Bacon manuscript, from Bednarski, 1931, fig. 7

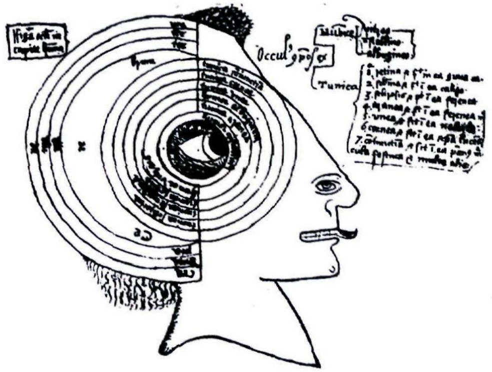


Fig. 16 – Ms Sloane 981 in British Library, from Sudhoff, 1914, table 1.

A tendency toward realism is shown in a remarkable sagittal cut through the head in a London manuscript (British Museum, Ms. Sloane 981). Sudhoff (1914, pp 3-6) describes it as a fourteenth century illustration made to a copy of a twelfth century ophthalmological book by Zacharius from Salerno. The box text in the upper left corner literally says: "the figure of the eye within the human head" *(figura oculi in capite humano)*. The concentric circles in the middle list all tunics and humors of the eye, the crystalline lens (humor cristallinus) being the central one. The larger circles toward the left indicate the major membranes of the brain (pia mater, dura mater) and the skull (craneum).

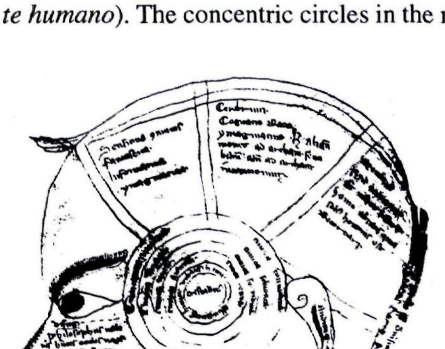


Fig. 17 – Eye-brain-representation in 14th century Vatican library manuscript, from MacKinney & Boyd, 1964, figure 6.

A fourteenth century anatomical picture from the Vatican library (MacKinney & Boyd, 1964, fig. 6 facing p 329) is more realistic and combines a detailed description of the eye with a detailed description of the inner senses. Again the "cristallinus" is at the center of the concentric circles which constitute the eye while for the brain the rigorous geometry is abandoned.

In the more popular accounts of the first printed books which include anatomical representation geometrization disappears and realism increases. In Reisch's famous *Margarita Philosophica* (1503) only two lines indicate the link between the eyes and somewhat convoluted brain ventricles. In Peyligk

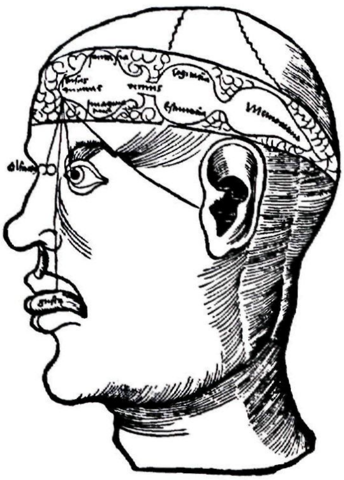


Fig. 18 – The inner senses as depicted in Reisch (around 1500) *Margarita Philosophica*, Ghent university library.

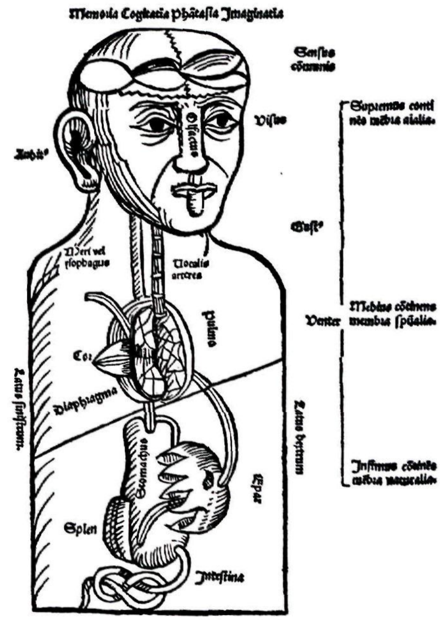


Fig. 19 – The inner senses as depicted in Peyligk (around 1500) *Compendium philosophiae naturalis*, from Sudhoff 1913.

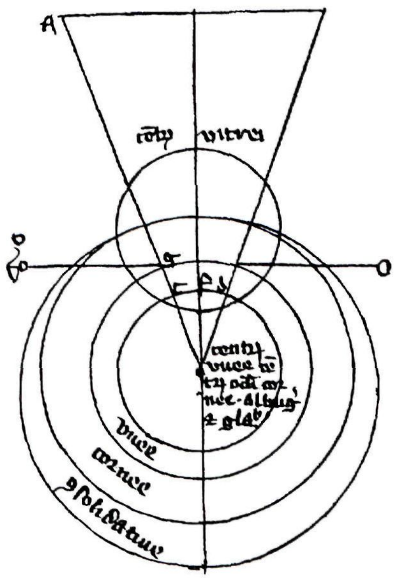


Fig. 20 – Eye diagram in Roger Bacon manuscript (Prague university library 1552), from Bednarski, 1931, fig. 3.

(around 1500), the first ventricles are even shown side by side (figure 19 from 1513 edition). Possibly, attempts to support the inner senses model with detailed anatomical data might have led to its more rapid decline. That is what one would infer from Vesalius' comments (1543):

> To this point I can in a measure reasonably follow the functions of the brain, through the dissection of living animals, with some degree of probability and truth. But I cannot understand to my satisfaction how the brain performs its office in imagination, reasoning, cogitation and memory - or however else you may wish (following the doctrines of I don't know who) to subdivide or enumerate the powers of the reigning soul. (Vesalius, *Fabrica*, VII.i, quoted from Harvey, 1975, p 30)

But with respect to the detailed anatomical description of the eye, geometrization is much more pronounced and longer maintained. The Western authors who are responsible for the promotion of Alhazen's theory and the expansion of *perspectiva* into a pivotal discipline in the thirteenth century are Roger Bacon, John Pecham and Witelo. Their books constitute the core of the perspectivist literature. The eye diagrams in these books express in various ways the main tenets of the perspectivist paradigm.

Foremost representative are the diagrams in Bacon's work, several of which include an indication of the visual cone as in the manuscript Nr. 1552 of the university of Prague reproduced from Bednarski (1931, p 63). As Bednarski points out: the eye is really dealt with as a mathematical figure. Bacon discusses the position of the centers of the various spheres involved. In versions available at the Bodleian Library in Oxford (figure 21, here MS Digby nr 235), these centers are represented as points. Obviously, the curvature of the layers is of utmost importance for the selection, at each passage through a refracting surface, of the rays which are supposed to contribute to the image.

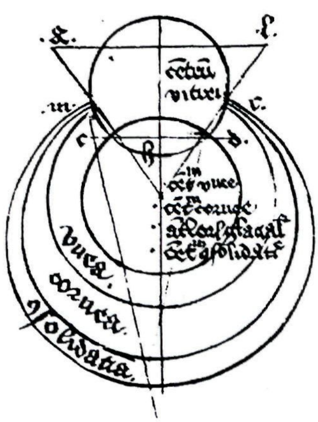


Fig. 21 – Eye diagram in Roger Bacon manuscript (Oxford university, Bodleian Library, MS igny 235), from Polyak, 1941, fig. 18.

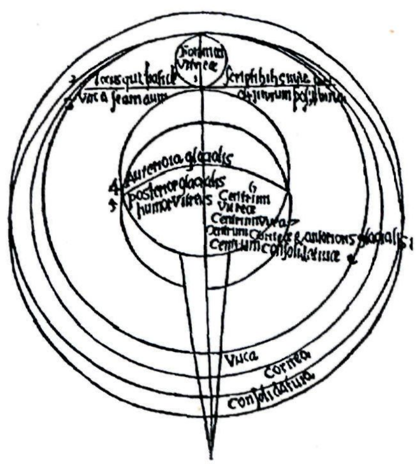


Fig. 22 – Eye diagram in printed version of Roger Bacon's *Perspectiva* (Frankfurt 1614), from Bednarski 1931, fig. 2.

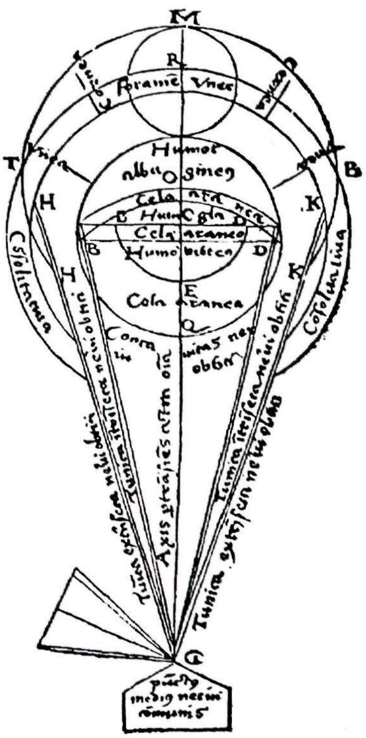


Fig. 23 – Early 14th century eye diagram in manuscript of Pecham's *Perspectiva* (Oxford, Bodleian Library, Ms Ashmole 1522), from Polyak, 1941, fig. 15.

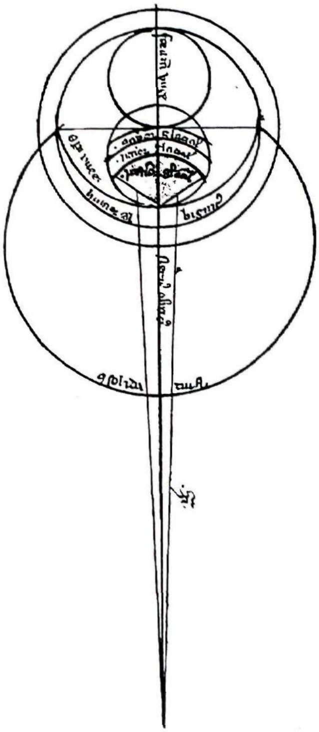


Fig. 24 – Eye diagram in first printed edition of Witelo's *Perspectiva*, from Bednarski 1931, fig. 16.

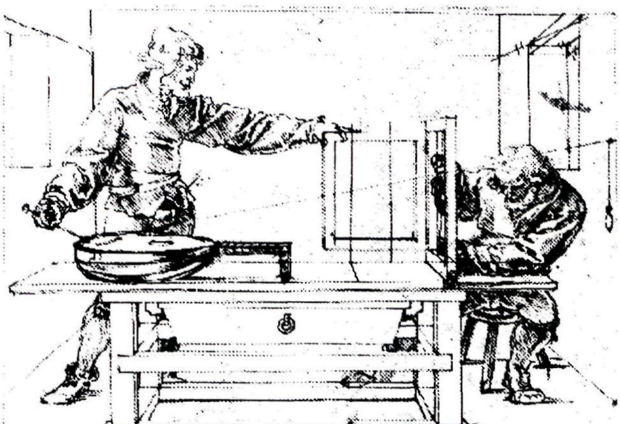


Fig. 25 – Dürer's *Underweysung der Messung*, 1525.

A printed version (as late as 1614) of Bacon's text on *perspectiva* has a clear indication of the labels and the location of the crystalline lens (*glacialis*).The popular text of *perspectiva* with a relatively wide distribution was John Pecham's *Perspectiva communis*. In an early fourteenth-century manuscript (Oxford, Bodleian Library, MS Ashmole nr 1522), the eye diagram has a similar structure, i.e. the crystalline lens slightly in front of the center of the spherical eyeball.

The more elaborated scholarly text was Witelo's *Perspectiva*. From the diagrams reproduced by Bednarski, we select only one (from the Nürnberg 1535 first printed edition) to indicate again the typical position of the lens. Here, the converging lines are meant to indicate the tunics of the optic nerve which leaves the eye. The small triangular structure below to the left of the visual axis represents the optic nerve of the other eye, both nerves coming together in the optic chiasma, indicated by the box.

On the whole, late medieval anatomical diagrams of the eye clearly exhibit their affinity to the Arab mathematical theory from which they originated. They are geometrized in order to explain the selection of the particular rays which obtain access to the inner structure of the eye and to explain their trajectory through the eye, up to the lens. They do not seem to be accurate realistic drawings of careful dissection.

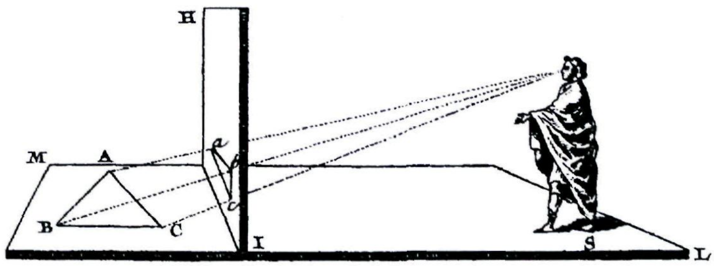


Fig. 26 – Perspective as illustrated in the encyclopedia of Diderot and d'Alembert, 1750.

1.4 The visual cone and linear perspective in art

Before looking at renaissance anatomical drawings of the eye and their development in the sixteenth century, it is worthwhile to realize how close renaissance linear perspective in art is to the Arab and late medieval theory of vision. In the application of rules of linear perspective as prescribed in Alberti's little book of 1436 the picture plane is nothing but a section through the visual cone, orthogonal to its central axis. The image on the picture plane is obtained in a way very similar to the way in which the object of vision is recomposed on the crystalline lens. In fact, this lens functions just like the picture plane of perspectivist painters. The standard examples to illustrate the artistic technique are Dürer's depictions of perspective devices (see figure 25). A simple illustration from the encyclopedia of Diderot and d'Alembert shows even the visual cone itself (see figure 26).

Although there are important differences, in general one can consider artistic linear perspective as a relatively late application of late medieval theory of vision. As a matter of fact, the terminology used by artists just indicated that: *perspectiva artificialis* or *perspectiva pingendi* (the perspective of the painters) was meant to be an imitation or a substitute for *perspectiva naturalis* or *perspectiva communis*. Linear perspective derived from a theory of vision much in the same way that AI (artificial intelligence) derived from notions on the nature of human intelligence. Maybe there is less consensus about a general theory of the brain and intelligence in cognitive science now than there was consensus about the perspectivist theory of vision then. But just as artificial intelligence is meant to provide computer copies of natural intelligence, so artificial perspective was meant to provide artificial vision (a painting) based upon some technical devices. Even the criteria for success as formulated by the pioneers resemble each other. Brunelleschi intended his painted panels to fuse with visual reality in the way Turing intended computer response to become indistinguishable from authentic human communication. However, at this point, one can wonder whether the perspective of painters had a similarly innovating impact on the study of vision as computer concepts have on the study of cognition and intelligence?

2. VESALIUS AND HIS RIVAL

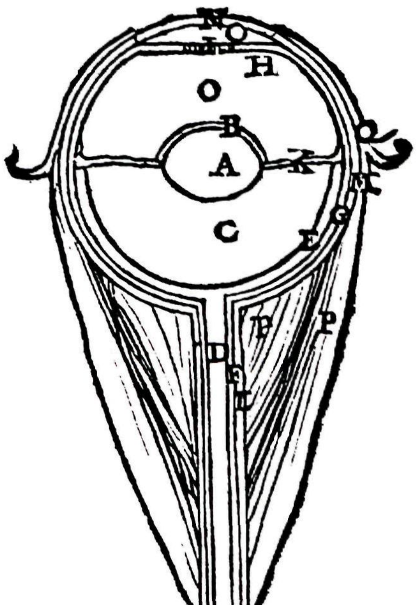


Figure 27, Eye diagram from Vesalius *Fabrica*, 1543, Ghent university library.

Standard accounts of the history of anatomy present Vesalius *De humani corporis fabrica* of 1543 as a turning point. It is the remarkable year in which Copernicus' heliocentric model illustrates the power of scientific reasoning. But in the same year Vesalius illustrates the power of careful observation and accurate registration. If Copernicus is a champion of daring theorizing, Vesalius is the champion of observation, and together they easily qualify as the founding fathers of the scientific revolution.

In the introduction to his text, Vesalius emphasizes the importance of observation, both for the scholar and for the apprentice. The apprentice comes to a better grasp of the materials when aided by good graphical representations which show things almost as real and the practice of dissecting equally contributes to proper understanding of the established medical literature. However, the scholar might even discover that it is possible to improve upon the knowledge of celebrated authorities. Vesalius praises Galen for his willingness to change views when observation would impose such changes, but he also blames him for not having actually pursued dissection of human corpses far enough to verify his own records. He refers to the embarrassment of physicians when, in an attempt to illustrate Galen's findings, they hit upon one or more of the more than two hundred errors he was able to count. He mentions how they are busily writing letters to each other about this, discussing their diverging findings in the hope of settling these issues of anatomical ambiguity or plain error. What image of the eye do we receive from an anatomist who is, both in his own terms and in terms of his popular reputation, the innovating proponent of careful observation and clear pictorial representation?

2.1 Vesalius diagram of the eye

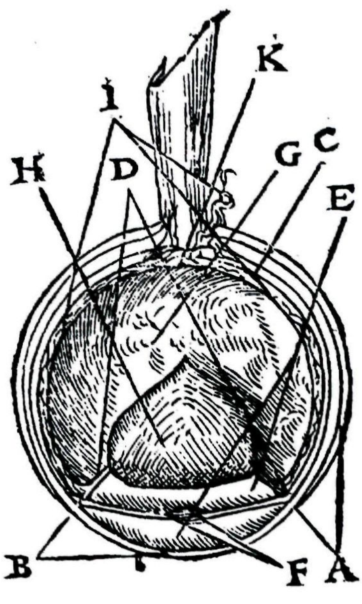


Fig. 28 – Eye diagram from Estienne *De dissectione partium corporis humani*, 1545, Ghent university library.

From the first edition in 1543 of the *Fabrica* onwards and throughout the editions that follow, the results of Vesalius anatomical study of the eye are presented in a typical arrangement which many other authors will follow. We will discuss the detailed arrangement further on. For our current purposes the most important figure is the diagram of the longitudinal cross section of the eye.

It is at once obvious that this is not the modern eye as it is depicted by Descartes. This is still the perspectivist scheme or even the Galenic one, at least with respect to the central position preserved for the crystalline lens. How can the major innovator of anatomy and champion of careful observation be so manifestly in error? Is this the revolution in scientific observation and pictorial representation or are we witnessing the top down ideographic forces at work? Is Vesalius picture of the eye possibly a vulnerable spot in an œuvre that on careful analysis would prove much more ideographic than its author would be willing to admit?

2.2 Estienne as an alternative to Vesalius

The publication of Vesalius' epoch-making atlas was no isolated event. It originated in the period in which printing of scientific texts was reaching full maturity and Vesalius had several rivals rushing to print with similar projects. One of them was Charles Estienne, who he had met while he was studying with the famous Sylvius in Paris. Estienne belonged to a family of established printers and had started to prepare a medical atlas with the help of a surgeon while he himself was still studying medicine. Several woodcuts could have been ready at the time Vesalius was in Paris, years before he published in this field. However, Estienne came in conflict with the surgeon about the copyrights of the pictures and the publication of his atlas was delayed for many years. When his *De dissectione partium corporis humani* finally came out in 1545, the first edition of Vesalius' atlas was already circulating for two years.

There is a chapter on the eye comparable to the one that Vesalius presented. However, the diagram of the eye is markedly different from the Vesalius one. Here, the crystalline lens might be overestimated with respect to size but with respect to location, it is much closer to anatomical truth. Nevertheless, Estienne's text does not suggest that he is on the brink of a revolutionary new view: he almost exclusively refers to Galen. And like Vesalius, he is stressing the importance of careful observation and his book of plates is meant to help one observe with his own eyes. Is he just a better observer than Vesalius, less vulnerable to ideographic transformation?

2.3 Rhetoric or scientific innovation?

In his *A Short History of Anatomy and Physiology from the Greeks to Harvey* Singer (1957, p 111) claims that "few disciplines are more surely based on the work of one man than is Anatomy on Vesalius." The numerous editions and imitations of Vesalius' atlas are indeed indications for the enormous impact of his work. But is this because of the medical merits of his publications?

Besides their medical significance, Vesalius' anatomical pictures also represent an artistic achievement. Edgerton (1985) has pointed out that Vesalius was not the first author to improve upon the aesthetic quality of anatomical diagrams by incorporating them into drawings of famous works of art. Already around 1510 Berengario understood that in rapidly expanding business of printed books, anatomical drawings of parts of the body would be better received if they could be situated into pictures and poses reminding the viewer of classical statues or paintings. But Vesalius apparently had the kind of taste and connections that gave him access to the best artists of his time. Independently of the question about who did the drawings for his atlas, whether John of Kalkar or Titian himself or another member of his school, it is obvious that Vesalius' impact is to a significant degree due to the great artistic qualities of his pictures.

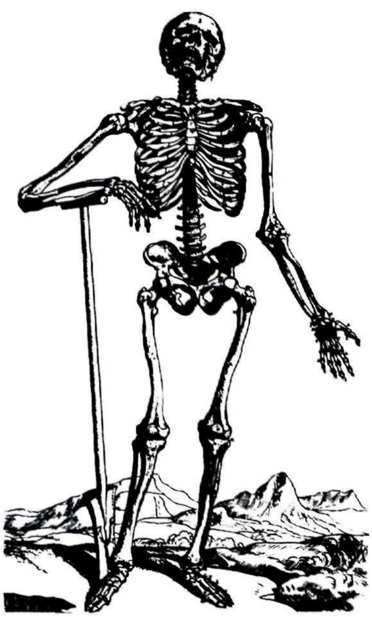


Fig. 29 – Skeleton from Vesalius *Fabrica*, 1543.

Take one of the best known pictures like the skeleton with the spade (see figure 29). The skeleton, leaning on a spade, is thereby associated with the idea of digging a grave, possibly its own, a theme resonating the medieval depiction of the macabre dance. The left hand is making a gesture of powerless acceptance while the backwardly inclined head bears an expression of immense tragedy on the face. These features give a dramatic unity to themes far beyond the bare anatomical facts which are the primary purpose of the picture. It captures the attention in some distracting way, even making us fail to see the awkward way in which the handle is connected to the spade. These features are rhetoric devices definitely enhancing the impact of the picture but largely on aspects that are irrelevant to the claimed content. There are many such subtle schemes in Vesalius' atlas which provide a hidden unity or coherence. As Herrlinger 1967, pp 110-111) indicates: the fourteen figures representing the muscle system are situated against backgrounds which together constitute a panoramic view of a hilly site in the Padua region. The displayed bodies are shown in lesser and lesser dynamic poses as the degree of dissection progresses. All of these make for fascinating pictures with the naive user of the atlas either being unaware of where his fascination stems from or attributing it to the scientific qualities of the representations. But the scientific specialists have reservations with respect to the scientific merits of the pictures. In their discussion of the skeleton, Saunders and O'Malley (1973, p 84) make many critical remarks:

Fig. 30 – Dissection of the brain in Estienne (1545).

> Although the skeletal figures are greatly admired, they represent many errors of proportion, some of which Vesalius himself recognized. The skeleton is that of a seventeen- or eighteen-year-old male, which has been reduced to approximately a fifth of natural size. However, the thorax is too short, the lumbar spine too long and the entire torso somewhat too short. The spinal curvatures, fully recognized by Leonardo da Vinci, are virtually absent, undoubtedly due to the Vesalian method of mounting the preparation, in which the vertebrae were threaded over a rigid iron bar thrust through the sacrum and bent quite empirically. As a consequence of the loss of the curves the ribs are too horizontal, giving the chest the balloon-like appearance of emphysema, and the normal pelvic tilt is diminished. The ratio of tibia to fremur is approximately correct. The arm appears to be too long owing not only to the shortness of the torso but as well to the forearm bones being too long for the humerus, which in turn, is too short so that the proportional length of upper limb to lower, or intermembral index, is far too low for a European subject. These proportional errors are not due to the effects of foreshortening from a low eye point but apparently from the application to the skeleton of one of the classical canons of proportion designed for the intact body.

Is this possibly an answer to the eye diagram as well? Is Vesalius more a master of presentation rather than of scientific scrutiny ? Grmek (1973, p 172) indeed claims that the Vesalian revolution is "plus d'ordre artistique que d'ordre scientifique." While in a comparison with Vesalius, Estienne might lose on aesthetic qualities, as far as scientific accuracy is concerned some of his drawings, such as the one of the eye, are definitely superior. He too joins the trend of locating his medical data into appealing pictures of the body, but apparently, he did not manage to hire the kind of artists Vesalius was able to cooperate with. Estienne can be linked with a more Nordic plain realistic way of depicting in the tradition of Wächtlin, leading into plates that are more cruel than elegant.

On the whole, this might allow for the hypothesis that Vesalius' success was due to his mastery of the medium while Estienne, being scientifically on a similar and at times even a superior level, became second rate because of a somewhat naive notion of realism and lack of better rhetoric devices.

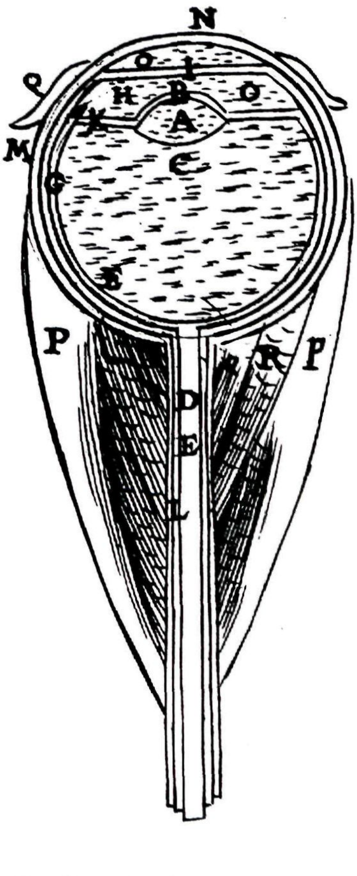


Fig. 31 – Eye diagram according to Valverde (1560).

If this were all the information we have, one would feel tempted to engage in an exploration of Vesalius case along the lines of Latour's study of Pasteur. In a controversial but masterly analysis of Pasteur's work on bacteria, Latour (1984) explodes any distinction between cognitive achievement and social opportunism in scientific discovery. Great achievements in science do not differ from political or military victories. They all come down to the orchestration of social forces in a way that the events take a course in which the discoverer, or politician or general, makes himself appear as the central hero. The ambitious scientist (or politician, or general) exploits such forces like a surfer uses the waves, skillfully riding on energies that are far beyond the strength of his own muscles. Vesalius would fit in such a scheme because his achievements, while presented as scientific, clearly include appeal to features and trends that are traditionally seen as non-scientific. The elegance of a drawing is irrelevant to its scientific accuracy. Latour rejects any such distinctions between scientific and extra-scientific factors. There is, as it were, no qualitative difference between a television commercial or a scientific experiment or a mathematical proof. They are all techniques to impress certain audiences and make them do whatever you want them to do: buy, applaud, imitate, ... In the combination of the various rhetorical techniques that go into their atlases, the Vesalius combination is more effective, i.e. more moving, than the Estienne combination.

The further development of anatomical diagrams of the eye in the sixteenth century illustrates that there is more to Vesalius' case than this rather top down interpretation seems to suggest. As indicated above, there is substantial development. Estienne is not the only one to come up with a more advanced picture.

3 FURTHER DIVERGENCE AND INTEGRATION AFTER VESALIUS

3.1 Valverde's anatomical treatise

Vesalius' anatomical atlas was widely noticed and had a very big impact. The most popular anatomical book however was published 1556 by Juan de Valverde who was a student of Vesalius at the time of the publication of the *Fabrica*. Valverde's anatomy which follows Vesalius model quite closely went through thirteen editions. It constituted a basic text for several translations, including one in Dutch, published by Plantijn in Antwerp in 1568. As such, its impact was undoubtedly equivalent to or even greater than that of Vesalius' original.

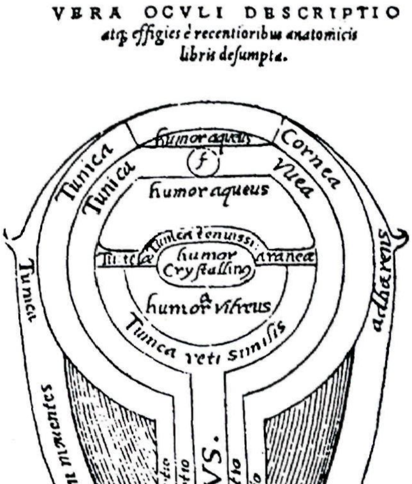


Fig. 32 – Eye diagram in Risner's 1572 printed edition of Alhazen's and Witelo's optical texts, from 1972 reprint, New York (preface Lindberg).

Valverde made a few modifications in style and content of the anatomical plates but when considering the presentation of the anatomy of the eye, one can understand Vesalius' complaint on Valverde's plagiarism. While the order of elements is slightly rearranged, the overall organization is clearly inspired on Vesalius and this applies throughout the whole book. But with respect to the question of interest to us, there is an important modification: the lens of the eye is moved to a more frontal position. The correction is introduced almost silently, without blaming Vesalius for substantial errors as was done at many other occasions and by other authors.

What is going on here? Is this observation silently prevailing on theory? Is this an author who is faithfully reporting what his eyes reveal, ignoring the doubt it might cast on the generally accepted theory ? However, if this would be the rationale, it is apparently not convincing everyone.

3.2 Risner's edition of Alhazen and Witelo

In 1572, a printed version of the pivotal perspectivist texts of both Alhazen, in Latin translation, and Witelo was edited by Friedrich Risner and published in Basel in one volume. Although the two texts contain a diagram of the eye, an identical picture is used on both locations. Obviously, it is a stylized version of Vesalius diagram.

At its second occurrence accompanying Witelo's text, there is a comment added to the picture stating that this is the genuine representation of the eye according to current anatomical books. Is this a kind of general recognition of Vesalius' authority in anatomical matters or is it an indication of ambiguity around what constitutes the correct picture of the eye?

If we look back at the pictures of the previous period, there is some reason to expect ambiguity since apparently, more is at stake than the mere location of the lens. If we look carefully, we see the shape of the lens change as well !

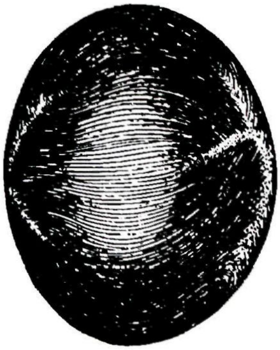


Fig. 33 – Helmholtz (1884) picture of lens removed from the eye, from Pirenne 1970, fig. 3.4.

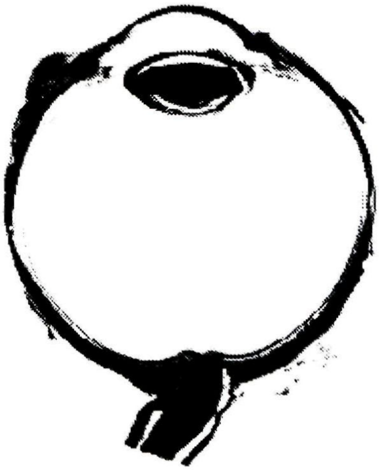


Fig. 34 – Photographic preparation of primate eye from Dowling 1987, fig. 1.3.

3.3 The crystalline humor obtaining a lens-shape

On closer inspection, there is an important difference between Estienne's eye diagram and Valverde's, although both seem to acknowledge the frontal position of the crystalline body in contrast to Vesalius central representation of this organ. In Estienne's drawing, the two halves of the crystalline body definitely have different shapes while in Valverde's drawing, we clearly have a symmetrical body.

The anatomical study of the lens of the eye is not at all easy. It is a very small part of the eye. If cut out to be studied in isolation, as indicated by Pirenne (1970, p 29), it takes on a more convex shape by virtue of its own elasticity. To study it in its natur-

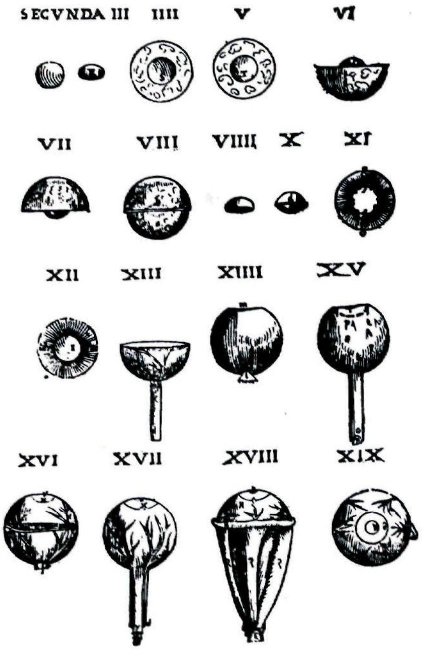
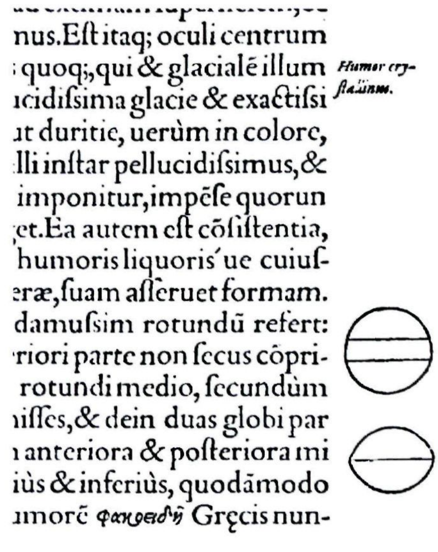


Fig. 35 – Vesalius arrangement of the parts of the eye in *Fabrica*.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imorē φακοειδῆ Gręcis nun-

Fig. 36 – Vesalius "marginal" drawings to explain the composition of the crystalline humor in Fabrica.

al location, one would need to dissect a frozen eye. One can only admire the painful scrutiny of anatomists like Estienne who persevere in preserving an asymmetry between the anterior and posterior halves of this tiny body. Modern anatomy partially supports the product of their sharp vision as is illustrated in Dowling (1987, p 8)

While Vesalius maintains a traditional separation between the two halves in the general diagram of the eye, the crystalline humor appears as an almost symmetrical body. In a sense, this means a double regression in his representation of the eye. The lens is not situated at the right location, neither is it shown in the correct shape. Nevertheless, a symmetrical structure seems accepted by followers like Risner, and an author such as Valverde amplifies the symmetry in the shape while correcting upon the location. However, there is a description and illustration in Vesalius text that explains this particular feature.

On the page that follows the one with the global scheme of the eye, Vesalius presents a stepwise detailed analysis of the various parts starting with the crystalline. It is shown separately, first in frontal view, than in lateral view. In views nine and ten, it is further dissected into two segments of a sphere and some connecting tissue. The other parts of the eye are assembled around it, totally according to the perspectivist view: the crystalline body in the middle as the central organ.

A particular feature however, that Vesalius explains in the text two pages further relates to the geometrical description of the crystalline body. There he includes a remarkable scheme in the margin to show the reader that he should conceive of the crystalline body as consisting of two segments of a sphere joined together. He takes care to demonstrate how the two parts are to be seen in relation to an entire sphere from which one should take away a disk in the middle so as to join top and bottom segments to form a biconvex lens !

This time, indeed a genuine lens is meant, not yet understood in its optical functioning but well known as a viewing aid for a substantial number of decades. Vesalius explicitly refers to the lens-shape, a word which itself is based on the term denoting the seeds of the lentil plant which have that prototypic biconvex shape. This is a remarkable turn indicating a development that is neither theory nor observation based, but technology driven ! It is the working viewing aid that comes to influence pictorial representation of a part of the eye. Apparently, anatomical analysis is yielding to a technical metaphor: the simple biconvex lens known for at least more than one, probably two or even three centuries in eyeglasses! Why is this only considered now ?

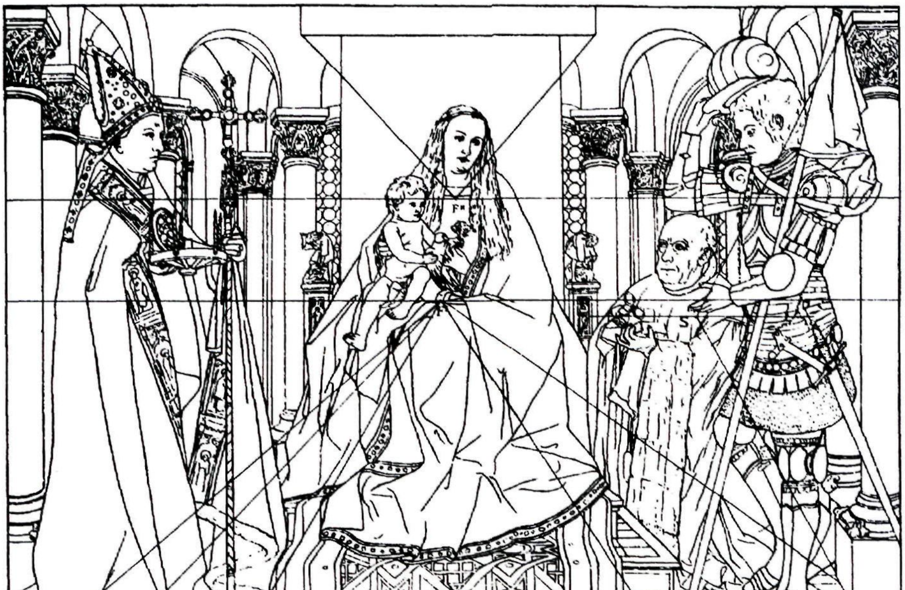

Fig. 37 – Jan van Eyck's "Madonna of Canon George van der Paele", 1436, Communal museum Bruges, line drawing from Kern 1904, table 5.

3.4 The origin of the lens and eyeglasses

Fig. 38 – Detail of eyeglasses in Jan van Eyck's "Madonna of Canon van der Paele", 1436.

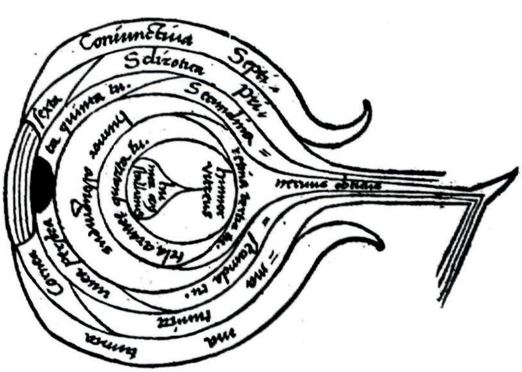

Fig. 39 – Eye diagram in original Reisch Margarita Philosophica.

The origin of eyeglasses is still largely unknown. There are various traces in documents and pictures which indicate that it is a thirteenth century event (Rosen, 1956; Ilardi, 1976). One is to be found in a painting from 1336 by Jan van Eyck which depicts the instrument in an already familiar form and as a common object at that time (see figure 37 and figure 38). But despite the fact that refraction was known and studied by perspectivists, the lens was apparently not the product of the application of their theories. Ronchi (1970, pp 70-71) suggests the accidental discovery in the world of the stained glass artists who should have found out the magnifying qualities of some of their small glass discs when they were inspecting them. According to him, both the name "lens" and the absence of any written recording indicate that the discovery occurred outside the scholarly community.

The term *lentis* is a popular word from the vernacular language to denote a common legume. And the rather remarkable lack of any record locating the discovery or discussing its impact can be interpreted as a refusal of the scholarly community to consider the lens as a legitimate topic within *perspectiva*.

Ronchi has had a sharp dispute with Lindberg and Steneck (1972) about how active the ignoring or repressing by scho-

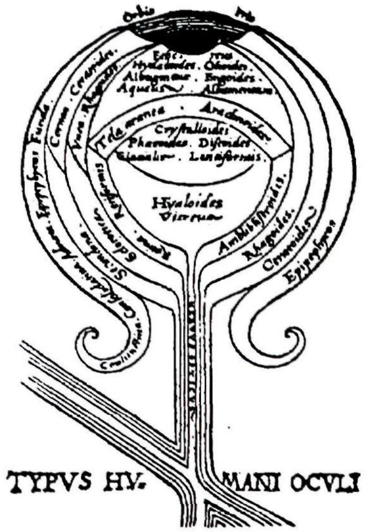

Fig. 40 – Eye diagram in Walther Hermann Ryff's *Warhafftige Beschreibung der Anatomie...*, Strassburg 1541, from Sudhoff 1907, fig. 5.

lars might have been. Lindberg and Steneck doubt whether the top-down influence of distrust in unreliable observation would be able to block exploration so drastically. It is true that Ptolemy and Alhazen dealt with phenomena of reflection and refraction under the heading "errors of vision." But as this did not impede an extensive treatment of various kinds of mirrors, why would it block serious analysis of eyeglasses ? It remains unclear why theory stayed behind in the presence of this simple technical device for so long. But we know that the technical device was there and we also have evidence that it was used in depictions of the eye even before Vesalius.

3.5 The lens as a pictorial metaphor in eye diagrams

The diagram reprinted in Fleck (1935) (see figure 1) is, as indicated by Sudhoff (1907), a modified version of the longitudinal cross section of the eye depicted in Reisch, one of the earliest printed encyclopedias from around 1500 that went through several editions. The Strassburg 1539 version as well as the original Reisch contain a representation of the crystalline body in which there is no symmetry between anterior and posterior part so that there is no suggestion at all of any simple convex lens-shape. It is the rotated or inverted falling droplet shape which we have also seen in Estienne's diagram. That is the common and popularized representation around 1500 !

Sudhoff (1907) reprints however another eye diagram from a sixteenth century anatomy book by Ryff equally aiming at a wider readership since it was published in both Latin and German. The Ryff eye diagram, printed two years before Vesalius atlas has an important feature by which it is in contrast with the Reisch-type pictures: a perfectly lentiform crystalline body or lens. It is even explicitly indicated with the labels filled in in the outline of the organ: lentiformis or lens-shaped. But notice also that while the shape has shifted, it is still the traditional perspectivist location: right in the center.

Sudhoff does not know whether Ryff himself drew the image or borrowed it from someone else. Singer (1956) refers to Ryff's acquaintance with Vesalius in Paris and the latter's complaint about Ryff's plagiarism. Independently of the question about who decided upon the importance of the lens-shape, the idea was apparently in the air. Sudhoff's comment on Ryff's picture might seem somewhat ambiguous: "Wie unvollkommen die Abbildung auch noch ist, so ist doch nicht zu verkennen, dass hier nicht nur "gelehrte" Belesenheit in der Häufung der terminologischen Varianten oder gelehrte Erwägung, also Denkarbeit sich ausspricht, sondern dass hier auch schon ein kleiner Durchschuss eigenen anatomischen Sehens, etwas Naturanschauung zutage tritt" (Sudhoff, 1907, pp 24-25). Given the fact that the German word "Anschauung" should not be reduced to pure sensory observation and involves conceptual insight as much as sensory data, Sudhoff probably takes the lentil shape as an indication of genuine physical insight ("Naturanschauung"). But, as we learn from history, it still requires many more steps to arrive at the proper picture. For us, it is important to know that the recognition of the crystalline body as lens existed before Vesalius and that it was apparently becoming the expression of a popular belief. Lindberg (1976, p 268, note 78) indicates that perspectivists too occasionally referred to a lenticular shape for the crystalline humor. But here we notice it as a prominent feature in a popular text. Since lenses were so useful in improving eyesight when used in eyeglasses, the tiny body in the eye which resembled them so much in shape should somehow also function in their manner. For Vesalius and Ryff, a popular technological metaphor might have become the convenient conviction for choosing among the alternative shapes for the crystalline humor.

3.6 Global metaphorical grasp without detailed understanding

Once the lens is no longer seen as a sure means to distortion but as a regular component in any vision system, including the eye itself, an extension of the analogy entails a reconsidering of functions. The Vesalian lens concept reflects an intriguing intermediate stage on the way to the retinal image model. Looking through a loupe and witnessing the magnification effect on the visual object is experienced as an increase in the powers of seeing. Therefore, seeing in general should be linked somehow with the functioning of a lens and the crystalline body, which looks like a lens, should also function as one, i.e. intensify, clarity or magnify. It is the undifferentiated visual experience which provides some global metaphoric understanding of a crucial part of the eye without any suggestion of detailed mechanisms. In this way, the step acquires a bizarre ambiguity: the crystalline body of the eye is correctly identified as a lens but there is no understanding at all of the functioning of this lens. In a totally misleading way, the crucial visual experience is still located somewhere within this central organ.

The step leading up to the diagram that is considered the appropriate representation of a longitudinal cross section of the eye is a more literal interpretation of the loupe-metaphor. When you look through a loupe or through eyeglasses,

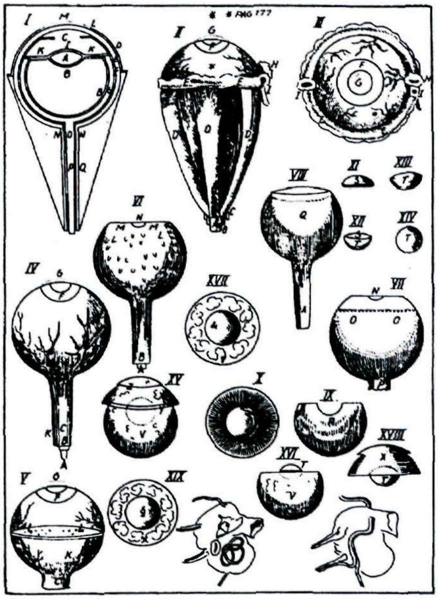

Fig. 41 – Eye diagram in Platter (1583).

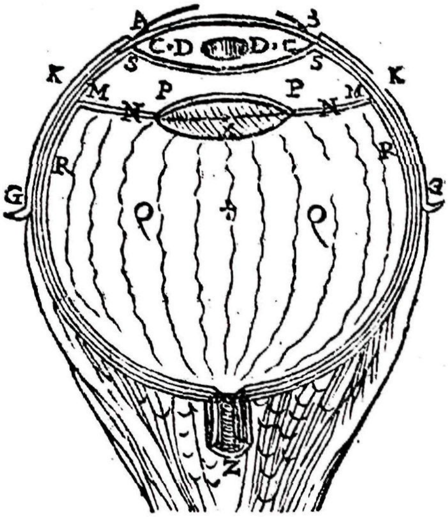

Fig. 42 – Eye diagram in Danti's (1583) extended edition of Vignola's *Due regole*.

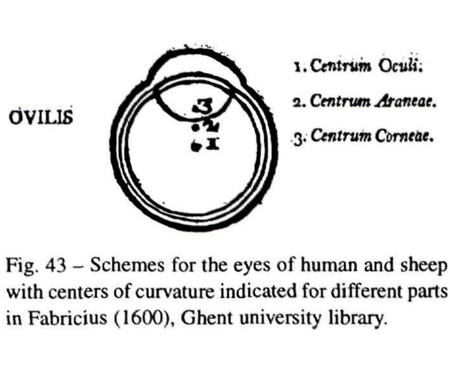

Fig. 43 – Schemes for the eyes of human and sheep with centers of curvature indicated for different parts in Fabricius (1600), Ghent university library.

the seeing is not to be located in the loupe or in the eyeglasses but in the eye that is behind them. Similarly, when there is a lens in the eye, the seeing should not be located in that lens but somewhere behind it. In an anatomical treatise published in 1583, Felix Platter, a physician of Basel, develops the point of view that the retina is the genuine receptor part of the eye where images from the outside world are received through the crystalline body functioning as an eyeglass to that retina (see Crombie, 1990, p 629). Platter's graphical illustrations of the anatomy of the eye are very much inspired by Vesalius' presentation but in the longitudinal section of the eye, the lens shaped crystalline body is clearly shifted to the frontal position. This is the picture that Kepler will quote to support the optically advanced modern theory of the retinal image.

Notice that despite the more or less correct drawing, the underlying theory is still based upon the global metaphor of the loupe without detailed understanding of ray trajectories. Platter's retina is still receiving an upright image through its magnifying glass !

That the lens-interpretation for the crystalline body had in the meantime gained widespread acceptance is also manifest from its presence in what Kemp (1990, p 82-83) calls "the most intelligent, useful and thoroughly informative book on perspective construction to have appeared by that date", i.e. Egnatio Danti's edition of Vignolla's *Le Due regole*, published in the same year as Platter's book, 1583. As a mathematician, Danti provided extensive comments on a text by a painter and architect who had died in 1573. As indicated by Kemp (1990, p 79), Danti added to Vignolla's remark that "the centre of the eye is the centre of the crystalline humour" an elaborated treatment of the functioning of the eye, including a diagram (see figure 42). Danti too locates the lens-shaped crystalline body clearly in the frontal part of the eye rather than in the center and he refers to Realdus Colombo (Vesalius successor in Padua) and Valverde as the discoverers of these features. However, as we have seen, both features were present in earlier drawings, be it not conjoined. That they are now integrated in a first rate treatise on artistic perspective as an innovation borrowed from famous contemporary scholars indicates that the eyeglass-metaphor, previously missed or ignored or suppressed during centuries, is now more and more adopted by the scholarly community at large, but without the support of detailed optical understanding.

4 CONCLUDING REMARKS

No new pictures of the eye are to be added in this development from the perspectivist to the retinal image model. That is not to say that there are no remarkable explorations which, in retrospect, have turned out to be dead ends, at least according to the established retinal image viewpoint. With Gibsonian sympathies, one could admire the impressive thoroughness with which Fabricius d'Acquapendente studies all aspects of vision, including eye movements, in a major treatise of 1600. But his diagrams of the eye tend to preserve the perspectivist doctrine in a kind of geometric comparative anatomy rather than in the ray tracing Kepler brings to bear upon the problem.

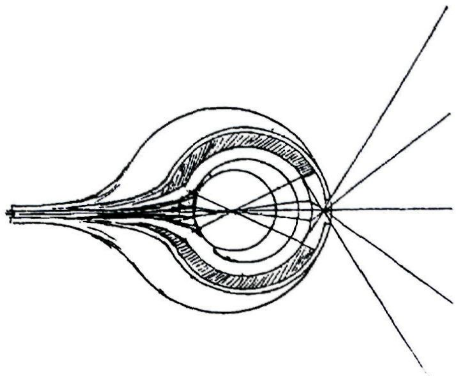

Fig. 44 – Eye diagram by Leonardo (1452-1519) exploring a double reversal of rays to preserve an upright image, from Sudhoff 1907, fig. 7.

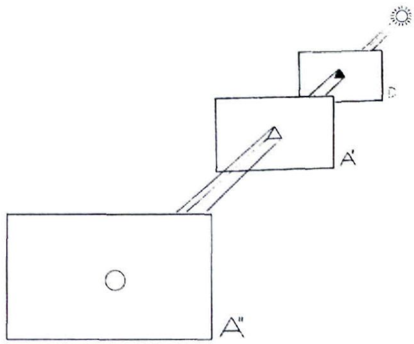

Fig. 45 – The basic enigma of pinhole images.

Kepler (1604) uses Platter's illustrations. And the scientific as well as popular illustrations for the Keplerian view are to be found in Descartes' (1637) drawings for his text on optics. However, there is another picture that might be relevant to Kepler's ultimate success in disentangling this complex issue.

4.1 Dürer's perspective treatise and Kepler's solution

Indeed, no basically new diagrams enter the picture between Platter and Kepler, but we might have skipped some relevant ones before Vesalius. Understanding the retinal image involves more aspects of ray tracing than we have been able to follow. An aspect which has been explored intensively is the camera obscura production of images, known as a technical device and straightforwardly applicable if it would not have produced an inverted image. Recently, Shigeru Tsuji (1990) even argued that Brunelleschi's panels, which in a sense meant the experimental discovery of linear perspective representation, must have been produced by means of camera obscura techniques. That inverted images were familiar can also be derived from Leonardo da Vinci's resolute attempts to find a second crossing of rays to reestablish the inverted image into an upright position, considered so obviously correct and normal (see figure 44). How did Kepler manage to be more successful in ray-tracing than Leonardo?

Kepler knew of the camera obscura which was used as an astronomical device to study eclipses and he wanted to investigate the precision of the data it provided. A crucial factor in the camera obscura is the size and the shape of the aperture. If one intersects the light rays quite close to the aperture, only a more or less blurred outline of the aperture is obtained but farther behind in the dark box, the patch of light will transform into the inverted image of the surroundings. The problem of pinhole images had been studied intensively by medieval perspectivists but they did not manage to arrive at a solid solution. The situation is quite familiar. On a sunny day in the midst of summer, look at the various patterns which sunlight produces on the ground when shining through the rich foliage of the trees. Amongst the jumble of shapes one would expect from light penetrating through such a crisscross arrangement of leaves, one also finds surprisingly regular circular shapes. For perspectivists, this was a major challenge since they saw it as a violation of the rectilinear transmission of light. How could rectilinear rays shining through angular apertures project into regularly curved images? Simplified, the situation can be represented by means of the following picture (fig. 45). The sun shining through the triangular hole in cardboard D produces a triangular patch of light when intercepted at location A', close to the cardboard, but a circular pattern at location A" farther away from the hole.

This is again a problem which makes one wonder why simple solutions can be so elusive. The circular shape is an (inverted) camera obscura image of the sun ! Perspectivists, with all their geometrical inventiveness did not hit upon a geometric analysis yielding that insight, in spite of their exploration of rays crossing in or behind the aperture. Toward the end of the sixteenth century, Maurolico provided an elegant geometric explanation of this phenomenon which he however did not publish and which was not known to Kepler. Disappointed with the explanations of the perspectivist like Pecham and Witelo, Kepler set out to study this problem more empirically. He used the technique D"ùrer suggested for the rigorous construction of perspective images, representing rays coming from the object by means of threads to determine the exact location of their intersection with the image plane (see figure 25). Kepler describes his use of this technique as follows:

> A certain light drove me out of the shadows of Pisanus (Pecham) several years ago. For indeed, since I could not comprehend the obscure sense of (his) words from the diagram on the page, I had to recourse to a personal observation in three dimensions. I placed a book on high to take the place of the shining body. Between it and the floor I set a table having a many-cornered aperture. Next, thread was sent down from one corner of the book through the aperture and on to the floor; it fell on the floor in such a way that it grazed the edges of the aperture; I traced the path produced and by this method created a figure on the floor similar to the aperture. Likewise, by means of a thread attached to another, a third, a fourth corner of the book, and finally to an indefinite number (of points) along the edge, there resulted on the ground an indefinite number of traced figures each having the shape) of the aperture, which together produced a great and four-cornered (figure having the) shape of the book. (Kepler's remarks on Witelo, in translation by Straker, quoted from Lindberg, 1976, p 187).

In combination with a theory of refraction that inflated the cone-concept far beyond what perspectivist ever dared to consider, Kepler could establish the retinal image as an inverted camera obscura type picture. An indefinite number of cones originating in each point of the source has the lens as common base. To each of these cones, linking the points of the source with the eye, corresponds a cone within the eye having the same base and a specific apex on the retina. In this way, the camera obscura image is constructed through a relatively large aperture that allows, through the refocussing qualities of the various refracting layers of the eye, to arrive at a sharp image.

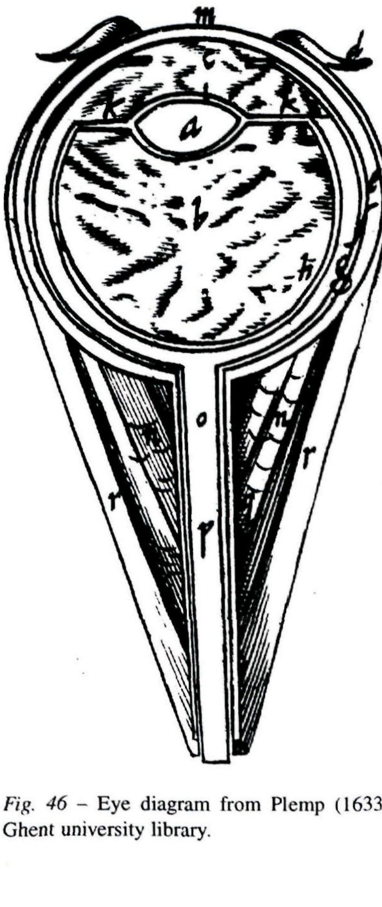

Fig. 46 – Eye diagram from Plemp (1633), Ghent university library.

Kepler does not quote Dürer directly, but it is highly probable that he was aware of the method and the drawing. If Dürer's picture would in fact have suggested the idea it would illustrate yet another aspect of the intriguing interaction between artistic and scientific representation. But its applicability also demonstrates an ambiguity which makes it difficult to evaluate Kepler's innovation.

For Straker (1981), Kepler's discovery qualifies as a first rate scientific innovation: a new paradigm indicating the onset of the mechanistic point of view in optics. For Lindberg (1976), Kepler's discovery means the ultimate perspectivist achievement, the successful completion of the visual cone paradigm. What we have witnessed in tracing the pictorial representations of the eye does not allow for such a radical classification in terms of entirely new or entirely old. Several times we have seen how relatively minor additions or changes of various representation schemes have gradually led to more substantial changes in the long run. If there is a characteristic which makes Kepler's achievement stand out as special, one would feel that a formal criterion might be more appropriate. In a sense, it is by applying the old view as a formal technique in a reflexive fashion that the new view is generated. By applying the perspectivist technique newly to an analysis of vision, Kepler managed to go beyond the perspectivist doctrine, both preserving some basic concepts and dramatically extending their scope. This makes us wonder whether it would not be more appropriate to reconstruct the cognitive evolution from the perspectivist to the retinal image doctrine of visual perception in Piagetian developmental terms rather than to impose Kuhnian terms on it.

4.2 The instrumentality of popularization to progress

Besides Descartes, one of leading scientists who was very eager to adopt the new theory of vision imposed by Kepler's discovery was the Louvain professor in medicine, Vopiscus Fortunatus Plemp (Plempius). In 1632, Plemp published a treatise on ophthalmology which was entirely based upon the retinal image model in stead of the perspectivist view. Yet, despite the geometric arguments involved, no single scheme or diagram can be found in this scholarly Latin work. In the same period, Plemp arranged a translation in Dutch of an anatomical text by Bartholomeus Cabrolus to which he added his own extensive comments and corrections. This work in his native language is amply illustrated and contains a Vesalius type arrangement of parts of the eye with a longitudinal cross section that is very much like Valverde's and Platter's (Plemp, 1633, p 222).

In that popular book Plemp indicates that almost all anatomist still consider the crystalline body to be the locus of vision. However he modestly claims for the alternative view that the retina is the appropriate location:

> In de crystallige vochticheydt, seggen al de ontleeders en genees-konstenaers, wordt het gesicht volbrocht. Het welck oft alsoo is, heb ick scherp-sinnichlijk ondersocht in mijn boek van't ooch, kortelingh in't latijn uytgegeven: al waer ick onweerspreeck'lijck (mijns dunckens) bewijs, dat het gesicht niet in de crystallige vochtigheydt, maer in't nette-vlies volbrocht wert. Verklaer mede heel wijt en breet het heer'lijck en recht wonderlijck maecksel van't ooch. Die der wetenschappen lief-hebbers sijn en latijn kunnen, mogen't lesen. De geleertheydt en lijdt niet, dat al haer geheymenisschen in't Duytsch uytgestort werden. (Plemp, 1633, p 221)

These final sentences are remarkable. Plemp refers to his own scholarly book on the eye in Latin indicating that science enthusiasts who know Latin are entitled to read it. Then he ends with the statement: "Scholarship does not endure that all its secrets are expressed in Dutch". From remarks in the introduction of the book, one could infer that indeed some protection of the secrets of the (medical) profession is involved. Plemp alludes to comments of angry colleagues criticizing him for throwing away medical expertise by making it accessible to common people through his translations into vernacular language. But undoubtedly there is also the common conviction we referred to in the beginning, i.e. that the ultimate carrier of knowledge is in the statements of some strict language. For the true scholar neither vernacular nor pictures are needed !

The development that we have been tracing is entirely in contrast with Plemp's attitude. At some stage we have seen pictures take the lead in representing relevant observational features that were still lacking from verbal theories. Moreover, these pictures turned up in popularization before they were seriously discussed in the scholarly community. However, it is not the pictorial mode as such which characterizes popular expression. Rather the popularity of a technical device, such as eyeglasses, leads up to a popular metaphor for explaining vision: the lens in its experiential aspects long before its optical functioning is understood. This three stage model from popular gadget over popular pictorial metaphor into scientific concept awaits more historical evidence, in particular with respect to early development and diffusion of eyeglasses. However, if sufficient support arises, another claim of Fleck seems more substantiated than his claim about the ideogrammatic nature of scientific illustrations.

Complementary to the notion of paradigmatic community or invisible college which are recently discussed labels for the inner circle of leading scientists or scholars in scientific specialties, Fleck discusses a segment of the society at large which he labels as the exoteric community. Traditional views see the community external to science only as a group of global supporters of science and ultimate end users of the results of science, in no way relevant to the internal developments of pure science. In the development of theories on the eye, we might be on the trace of some genuine interaction between the esoteric inner circle of science (the scholars) and the exoteric outer circle of common people. Apparently, the lens is taken up first by the exoteric community through its acceptance of eyeglasses and forced upon the esoteric community through the subtle pressure of scientific popularization. This might seem an impossible sequence: popularization before discovery! Yet this supposed popularity of lenses is what should come close to the kind of social forces Latour (1984) has in mind when he tries to explain Pasteur's use of societal movements. Popularity in the community at large is used to increase the momentum of a technique, or image, or concept, after which it is introduced or brought back into esoteric science (in Pasteur's case the laboratory) to assume a crucial role there (possibly in an experiment). It shows the society at large fulfill an active role in the internal development of a science. In the pictorial representation however, we discover a way for a social force to transform into a scientific concept. Since this is the requirement. Science cannot be reduced to the net result of the interplay between social forces. Social forces have to be rendered in a common form or medium that allows them to interact with scientific concepts. That is the task and challenge for the cognitive approach in science studies and cognitive psychology of science.

In the background of an esoteric scientific problem there are always various practices, techniques, images, fears, concepts ... which do not interact in the exoteric sphere. They are expressed in different modes, some as technical contraptions in terms of material equipment, some as striking images in terms of pictorial symbols, some as action patterns in terms of habits or social procedures, some as opinions expressed in common language. Only when rendered into some common representational medium they come to interaction according to the kinds of logic investigated by Piaget. They might add up or multiply or combine with each other in many other ways, including operations such as negation and suppression. As in the case of the lens and the eye where the newly transformed image ultimately destroys an old concept. The picture anticipating the theory is not mere rivalry between the pictorial and the verbal mode. It brings us on the track of such ongoing recasting process. The cognitive relates to this issue of rendering various factors or forces into a common medium in which they can interact. Previous case studies in the psychology of scientific discovery have brought to light the dense heterogeneous representations involved (Gruber, 1981). Whether the unification device should still be Plemp's imageless Latin, Fodor's language of thought or Minsky's (1991, p 373) yet to develop new specialty of "the presently unexplored domain concerned with communication between systems that use different representations," further case studies of scientific development might help to dissolve.

University of Ghent
Blandijnberg 2
Gent 9000

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