A noncyclopean diagram of binocular vision in strabismology*

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Abstract. Most diagrams concerning binocular vision and squint contain the cyclopean eye, which is a vestige of the 2000-year-old projection theory. The author’s previously published diagram is based on a motor theory of spatial localization which was been formulated by Descartes, Lotze, and Roelofs.

Introduction

It is difficult to explain the sensory phenomena of squint without the help of a diagram. Such a scheme usually contains the “cyclopean eye”, representing two superimposed retinæ (Fig. 1). In the case of normal retinal correspondence, both retinæ cover each other and both foveæ coincide. When correspondence is anomalous, one retina is shifted in respect to the other, and the foveæ do not coincide. Such useful diagrams, which date from von Tschermak, can be found in many textbooks [8]. The excellent didactic text of Burian and von Noorden [2], however, does not contain cyclopean diagrams. Why not? The answer is probably that the cyclopean diagrams are too reminiscent of the so-called projection theory, a theory which Burian strongly (and rightly) opposed.

In this paper the 2000-year-old projection theory is compared with a physiologically more acceptable sensorimotor theory of spatial localization. The diagram presented by the author is derived from the ideas of Descartes, Lotze, and Roelofs.

The projection theory

According to the projection theory, spatial vision comes about through projection of the retinal image into the visual world, more or less along the same lines that brought the rays from the object to the eyes. It is an ancient idea that vision results from something entering the eye – “immission” – and another thing “emitted” from the eye. Plato described it in his Timaeus: Colors come from the objects to the eyes, but the eyes at the same time emanate “fire.” Daylight and fire coalesce (synaugeia) to a “single homogeneous body,” stretching from the eye to the visible object. It is true that Plato’s pupil Aristotle held that the eye had only a passive, receptive, function, but most Greek theorists (Euclid, Ptolemy, Galen) emphasized the active emission of rays, or pneuma. Alhazen, who was the first to construct in the eye an image of the external world, adopted Aristotle’s immission theory. His book Perspectiva was influential among the medieval writers on optics, the “perspectivists.” But the old emission theory was not abandoned. Species (forms) entered the eye, but there were also “intentional species” in the opposite direction. Roger Bacon held the view that the power of sight emanating from the eye was required to “ennoble” the incoming rays, thereby rendering them capable of stimulating sight.

The emission theory received a new impulse after Kepler’s discovery of the inverted retinal image. The question arose of how the inverted image could be put upright again. It could be accomplished by an observer inside the head, a “homunculus” looking at the retinal image, but this leads to an infinite regression. A much simpler solution of the problem was to send the rays back into space along the same path on which they had arrived at the eye!

The projection theory, although clearly untenable, has remained with us until the present day. Johannes Müller [10], with this theory of the “self-intuition of the retina,” was not the last physiologist to localize space perception in the retina. Bourdy [1] believed that the directional values of retinal elements depended on receptor orientation.

Binocular vision provided a minor problem to the projection theory. As Helmholtz [5] and Hering [6] realized,

Fig. 1. Diplopia in left-sided esotropia with dysharmonious anomalous correspondence. C, Center of visual directions in the cyclopean eye; F, fovea of left eye; P, binocular pseudofovea of left eye; L, image of light on left retina; FCL, angle of squint; PCL, angle of diplopia; FCP, angle of anomaly

* Dedicated to Dr. G.K. von Noorden on the occasion of his 60th birthday
the rays from a near object to each eye were not parallel and were different from the binocular visual projection. But the hypothesized cyclopean eye, as the center of projection, solved that problem without deprecating the theory. Donders thought in cyclopean terms. In 1864 he wrote: "[The retinal stimulus] must be conveyed to the fibers of the optic nerve, communicated to the brain, and again, in an inverted direction, projected outwards [4]."

Von Tschermak's strabismological diagrams [12] belong to the traditional framework of the projection theory, even though he formally abandoned the theory in favor of his "exact subjectivism." By limiting himself to psychophysics, he blocked the road to the physiological analysis of spatial behavior, not only for himself but also for his many pupils. Cyclopean pseudoproblems are still abundant in the doctrine of the horopter, and Julesz [7] gives the title role of his celebrated book to Polyphemus. It is difficult to renounce an old creed!

In modern textbooks on strabismus the projection theory lives on in the diagrams. Since the ideology of the theory has been forsaken, some of these diagrams have become degenerate. A retinal element then projects somewhere through the sclera into space.

The motor theory of spatial localization

Descartes

Descartes was the first to propound a physiological theory of vision. He described the path from a sense organ through the central nervous system to an effector organ. His physiological concept avoided the intervention of the soul. He had no other choice, because he considered all organisms — except man — pure "automata." Hence, for Descartes the problem of optical localization in space could be formulated only as follows: If a cat sees a mouse, how can he catch it with its paw? Figure 2 (from Traité de l'Homme, 1664) shows his program for a motor theory of localization. The arrow stimulates the eye; the impulses in the optic nerves induce two efferent innervations in the brain: The eyes "foveate" and the finger points at the arrow.

It took two centuries before Descartes' revolutionary view was elaborated. The man who took up the challenge was Lotze.

Lotze

Lotze, the most prominent German philosopher in the post-Hegelian period, provided a motor theory of spatial localization in his Medicinische Psychologie [9]. It is the well-known theory of "retinal local signs." Lotze regarded the local signs as the postal code of the retinal stimulus. From all directions letters converge to the main post office (the nonspatial soul, in Lotze's view) where they are sorted. Then they diverge to their destinations, the muscles, which "reconstruct" the spatial order.

For this reconstruction Lotze concentrated on the eye muscles, first, because it is a long way from the retinal stimulus to the pointing finger, and second, because it is far easier to analyze the relation between the projective geometry of the retinal image and the polar coordinate system of the eye movements. He did not, however, believe that movements of "foveation" were the sole clues to spatial localization: Peripheral retinal elements created a "Bewegungstriebe," a latent impulse to movement, contrib-

![Fig. 2. The relation between sense impression and motor response, according to Descartes](image)

uting to localization in the same way as an impulse that had been carried out.

Although the neutral term "local sign" has been generally adopted, Lotzé's motor theory of spatial localization did not meet the response it deserved. There were three reasons for this; two of them are trivial.

In the nineteenth-century dispute between empiricists and nativists, Lotze had taken sides with empiricism, which was largely refuted by Hering and his school. Further, Lotze had emphasized the importance of myosensory information for our sense of space. Helmholtz, however, demonstrated conclusively that afferent stimuli from the eye muscles were of little importance in spatial vision. Even today, (for instance in Burian and von Noorden's book [2]) any motor theory of localization is considered a theory based on myosensory information and subsequently refuted because of this nonrelevant detail.

The principle reason, however, why Lotze's ideas did not penetrate was that he was not understood. The idea that the spatial structure of the retinal input had to pass through a nonspatial point to be subsequently reconstructed was incorrectly regarded as an outgrowth of post-Kantian metaphysics. Lotze was a spiritualist, indeed, but his aim was to formulate psychological principles based on the natural sciences. He had no other choice but to step over to psychology somewhere in the middle of visuomotor information processing. Nothing yet was known about cerebral mechanisms, and, for that matter, what do we know, ourselves, about the physiological machinery operating between the retinal stimulus and the spatial response? Lotze took an important step in assuming that the psychological correlative of the physiological process of localization must be located somewhere in the middle between the input and the output of the information processing. This was very different from the reasoning at his time.