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SOME OBSERVATIONS RELATING TO THE KINEMATICS OF THE EYE

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The kinematics of the monocular eye positions have been known for well over a hundred years. Donder's and Listing's Laws are discussed in most texts relating to the physiology of the eye. Helmholtz [1], Burmester [2], Lamb [3] and very recently Westheimer [4] have provided us with various mathematical treatments of the known relationships.

It is the purpose of this paper to describe some experiments designed to test the stability of the kinematic relationships and to suggest a theory which relates the geometry of the eye, the eye, muscles and the known facts of the kinematics of the eye.

Experiments were performed to answer the following four questions:

1. Does the primary direction vary with tilt of the head about the base line (the line connecting the centers of rotation of the two eyes)?
2. Does the primary direction vary for various fixation distances?
3. Does the primary direction vary with rolling of the head (inclination toward one shoulder)?
4. Can the primary direction be moved?

The after image method of locating the primary direction was used. The position of the primary point was approximated and a vertical strip of black paper was mounted at this point. With the head held in a fixed position the induced after image was observed as the point of regard swept (jumped) along a plumb line. The strip was adjusted laterally until the after image remained superposed on the plumb line throughout its length. A similar procedure was used for a horizontal strip and a horizontal line. A specially constructed yoke permitted one to tilt the head about the base line and to hold it fixed at any desired setting. Tilting

the head $\pm 5^{\circ}$, $\pm 10^{\circ}$, $\pm 15^{\circ}$ and using fixation distances of 1 meter, 50 cm., and 33 cm., the primary direction of two right eyes (my own and my assistant's) remained fixed with respect to our heads. These experiments answered questions one and two in the affirmative. This result indicates that the tonic impulses set up in the central nervous system by tilting the head and by accommodation did not affect the primary direction.

Helmholtz answered the third question in the affirmative and I have verified this in my own right eye. This adds additional evidence to the non-interference of tonic impulses and introduces additional evidence that changing the muscle relationship does not change the primary point. When rolling the head, the human eye will undergo a partial compensatory cyclorotation (about 5 degrees in my own eyes) which will alter the relationship of the muscle planes and the coordinates of the head. In spite of this the primary point remains fixed respect to the head.

Now for the final question. The primary point can be located reasonably well by just pointing to it. It is the point which is subjectively "straight ahead". If a pair of prisms, their bases to the right, are placed before the eyes, objects located straight ahead lies slightily to the left of body straight ahead. On several days I have located my primary direction and then worn a pair of six diopter prisms, base right for eight hours. Upon removing the prisms and again measuring the location of my primary direction, I find that it has moved to the left. By the next morning the primary direction is back in its original location.

It is of interest to report that the primary directions of my right and left eyes diverge by an amount very nearly equal to my distance phoria.

To summarize these experiments: the primary point seems to be quite rigidly fixed with respect to the head even when certain neuromuscular relationships are altered. The primary point can be moved, however, by artificially producing a new relationship between the bodily perceived world and the visually perceived world. The adjustment and re-adjustment seem to take place rather quickly.

The question now arises are the kinematics of the eye established entirely by some process of conditioning? The results of the final experiment would suggest that this is quite possible. However, the physical relationships of the muscle planes of the recti muscles to the eye do suggest that a close approximation to the facts are "built into" the system and only minor adjustments are necessary.

That this is true was suggested to this author by a recent analysis of eye positions given by Boeder[5]. Boeder used a stereographic projection of the meridians of the eye to point out certain relationships in the kinematics of the eye. It occu-

rred to me that if the recti muscles were stereographically, so to speak, connected to the eye and the orbit, the kinematic laws of eye position would by obeyed automatically. Such an eye would have four thread like muscles inserted at the anterior pole of the globe. The muscles would hug the exterior surface of the eye and have a common origin in the orbit at a point tangent to the posterior pole of the eye when the eye was fixed in its primary direction. These four muscles, acting on a perfectly spherical eye with no other attachaments, would position the eye in perfect accord with the described facts. No obliques would be needed, except to introduce cyclomovements in response to body orientations. In fact our own eye is not very far removed from this basic design. The insertions have been moved back to allow a clear view through the cornea, and, of course, nerves and blood vessels have been attached. For limited eye movements, approximately twenty degrees from the primary direction, these complications will not introduce serious errors. The origin has been moved back into the orbit and displaced twenty-two and one half degrees nasally. This is enough change to destroy the perfect kinematic positioning and throw the primary direction twenty-two and one half degrees temporally, but we still have those oblitgues make any corrections that may be needed. Also the recti muscles have finite width, a factor which permits each to introduce some rotary movement about the line of sight.

The visual primary direction and the proprioceptive primary direction (such as even a blind person must possess) are constantly being unified in each individual as he moves about in his environment and handles objects. It is suggested here that these two are closely related by the particular relationships which exist between the anatomical connections between the head and the eye- the approximate stereographic attachment of the recti muscles. The errors introduced by the lack of perfect stereographic connection mus be corrected by a process of continuous conditioning, mainly by the action of the obliques.

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