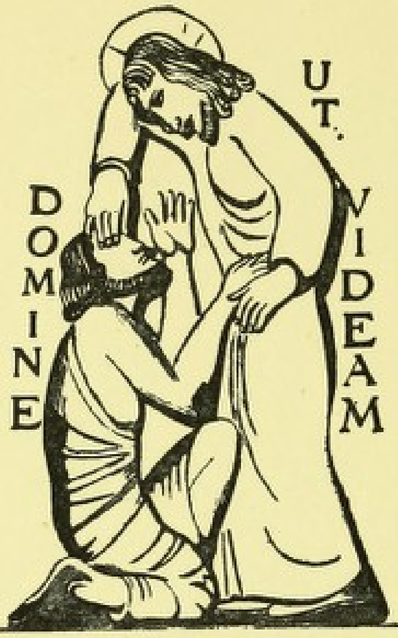
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# TESTS AND STUDIES

OF THE

# OCULAR MUSCLES

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BY

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WITH 110 ILLUSTRATIONS

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# PREFACE TO THE THIRD EDITION

That a second edition of this book should be asked for affords pleasant compensation for the time and thought it cost.

In the choice of terminology, I have carefully refrained from the dislodgment of ancient landmarks. Thus the words "adduction" and "abduction" will be found retained in their time-honored sense—a sense which is stamped on the very name of "abducens" muscle itself, and the dislocation of which would make the classics of Graefe and Donders, Helmholtz and Mauthner less intelligible.

The announcement, by one author and another, of supposed errors in the treatment of Listing's law by Donders and by Helmholtz have compelled me, even in these uncontroversial pages, to enter more fully into the laws of the parallel motions of the eyes than their clinical importance would perhaps otherwise warrant. The purely clinical reader can, if he prefer, pass over the section which shows these discoveries to be groundless.

My thanks are due to Dr. Asher, of Leipsig, for several suggestions from the German edition, one of which has led me to add a chapter on Nystagmus.

E. E. M.

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# TESTS AND STUDIES OF THE OCULAR MUSCLES

## CHAPTER I

### The Globe and Its Socket

The motions of the eyes are notable for their combination of silence, swiftness and precision.

The *silence* of the eye, or, at least, the absence of audible sound, is all the more remarkable because of the proximity of the organ of hearing and the ready conduction of sound by bone.

The *swiftness* of the eyeball itself is not, perhaps, greater than that of adept fingers, nor is it desirable that it should be in the interest of its delicate contents; yet the act of winking or "twinkling of the eye" has always been accepted by common consent as the briefest measure of time expressible by the human body.

The *precision* of the ocular movements, together with the perfect co-ordination of the two eyes, is the most important virtue of the three, and is evidenced in thousands of ways every day. One example only need be given, namely, that in watching a small moving object in the distance, such as a bird a mile away, it is seen single instead of double, which could not be unless both eyes followed the object with the keenest exactness.

Akin to this we may mention the steadiness of the eyeball in observing a fixed point; a steadiness, however, which is not inherent in the ocular muscles, but which is maintained by an exquisite "visual reflex" mechanism.

When the eyelids are closed the globes are in almost perpetual motion, as any reader may verify by laying the tips of his fore-fingers over the closed upper lids: moreover, if one eye be covered while the other is observing with comparative steadiness a fixed point, the covered eye does not share the steadiness of its fellow, but wavers slowly from side to side. This is easily demonstrated by the author's "visual camera" (Chapter XIV), which detects the movements of an eye placed in the dark.

Even in the light, an eye is unsteady unless occupied with a fixed object, as when, for instance, it only sees a false image of an object, the true image of which is seen by the other eye.

The absolute steadiness of the eye during the study of minute objects, is entirely beyond our voluntary control, and I think we may fairly describe the parts played by volition and reflex action respectively, when we say that the former *directs* the eye, and the latter *steadies* it. It is true that in daily life the point of fixation is constantly on the move, but then it does not move in a wavering way, but purposefully, and in looking at an object it flits, as it were, from one salient point to another, dwelling upon each long enough to let the mind grasp the new picture presented each time. Lamare's ingenious plan of making the movements of the eye audible by a kind of binaural stethoscope attached by a point to the upper lid, showed that four or five slight movements take place during the reading of one line, and a greater movement when we begin to read a new line.

Under ordinary conditions we can turn our eyes at pleasure from one object to another, but there is a peculiar pathological state in which this faculty fails, and in which this visual reflex appears to gain the upper hand, so that the eyes can with difficulty be made to look away from the object last looked at. To this subject we shall recur later on.

**The Ball of the Eye.**—When we consider the spheroidal shape of the eyeball, and the character of its motions, we need not wonder that astronomical language has been so freely drawn upon for their description. Thus we speak of the *globe* moving in its *orbit* (metaphorically like a planet), and distinguish its *axis*, *poles*, *meridians and equator*.

The *anterior pole* is the mid-point of the cornea in front: the *posterior pole* the mid-point of the sclerotic behind (as in Fig. 1).

The *axis* of the eye, often called the "optic axis," extends between these poles.

The *equator* is a circle or belt of the globe midway between the two poles.* (Fig. 2.)

The *meridians* are circles, each of which passes through *both* poles so as to have the axis of the eye for their common diameter.

In the study of the ocular motions we assume the eyeball to be

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* This definition of the equator is an anatomical one. Physiologically, its axis coincides with the visual line, if we think of vision; or with the fixation line if we are occupied with the ocular motions. Since the eyeball is not a geometrically true body, it is customary to disregard the little discrepancies between the position of the anatomical equator and those of the visual and fixation lines.

spherical, though it is not strictly so, but flattened from before backwards, more like an "oblate spheroid," interrupted by the prominence of the cornea in front, which has a stronger curvature.

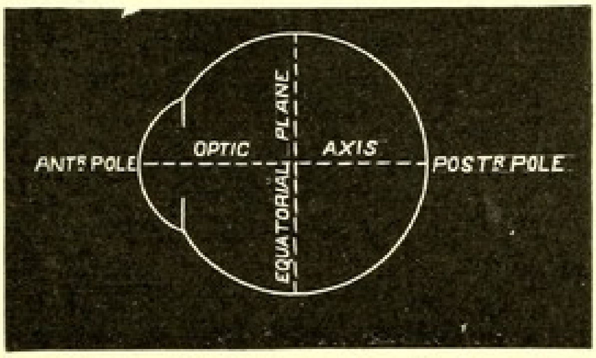


Fig. 1

**Ocular Muscles.**—Each eyeball receives the insertions of six muscles, namely, four recti and two obliques.

The *recti* have an almost common origin around the optic foramen (embracing the optic nerve at its entrance into the orbit) and course forwards, diverging as they go to embrace the globe for a short distance before reaching their insertions.

The superior and inferior *oblique* muscles act upon the eye from the upper and lower corners respectively of the inner wall of the orbital outlet.

The motions of the globe take place unerringly under the guidance of these six delicately-proportioned muscles, the importance of whose contribution to our daily comfort is not realized till one of them is disabled from any cause, and we see double.

**Normal Motions.**—The eye is so suspended in position that its ordinary movements are limited to those of *rotation*, no appreciable *translation* being possible. It is true that certain animals possess a "retractor muscle of the globe," capable of drawing the eye deeper into the recess of the orbit, but in man, *exophthalmos* and *enophthalmos* are only known as pathological conditions, due, in part, to such causes as variations in the size of the palpebral aperturo, varying pressure of the lids, varying tone of the extra-ocular muscles; turgescence or spasm of the retro-ocular blood vessels, spasm and relaxation of the unstriped "orbital muscle" of Müller, which spans the spheno-maxillary fissure; and possibly also to contraction or relaxation of the unstriped muscular fibres described by Sappey as existing in the internal and external check ligaments near their orbital insertion.

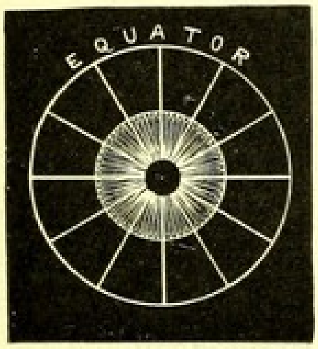


Fig. 2

It is probable that there occur, even in health, slight unnoticed physiological variations in the prominence of the eyes.

**Orbits.**—The orbits are two deep conical excavations in the skull, the anatomy of which is too well known to need description.

At the apex of the cone are two apertures, the optic foramen and the sphenoidal fissure, the former transmitting the optic nerve and the ophthalmic artery, the latter *all* the other nerves but one, and the ophthalmic veins. The inner walls of the two orbits are almost parallel to each other, but the outer walls slope outwards so strongly that the *axes* of the two orbits (represented by imaginary lines from the apices to the centers of the orbital outlets) diverge from each other by from 24° to 30°. The conical *shape* of the orbit is to accommodate the cone of muscles, and its apparently superabundant *capacity* is to permit the globe to be sufficiently packed in with orbital fat which plays a very important part in the formation of its socket.

The orbital *outlet* is narrowed a little by the incurving of its upper and outer margins, and its outer margin is considerably posterior to its inner. From a series of measurements which I have made, the outer margin of the bony orbit appears to be, on an average, about 22 mm. behind the root of the nose, 12 mm. behind the anterior ridge* of the lachrymal groove, and even 7 mm. behind the depression for the trochlea of the superior oblique. A needle run transversely inwards athwart the outer margin of the orbit would, it is said, pierce the center of an average eyeball. But great differences exist. The orbit is 1¾ inches deep, while its outlet is 1½ inches broad and 1¼ inches high.

It is evident that the large size and conical shape of the orbit would make it by itself a most unsuitable socket for the eye to work in; but, as a matter of fact, the eyeball comes nowhere in contact with it, and it may be regarded rather as a strong scaffolding for the real socket, as well as a storehouse for the orbital contents. The real socket is the capsule of Tenon, in conjunction with its supporting bed of orbital fat, supplemented by the concave surface of the eyelids in front.

**Tenon's Fascia.**—*All* the structures contained within the orbit are invested by sheaths derived from *one and the same* aponeurosis. The cornea, which, at first sight, appears to be an exception to this

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* The ridge referred to is the front edge of the groove formed by the superior maxilla and lachrymal bone.

rule, is not, of course, strictly within the orbit. This "orbital fascia" is in some places or parts of it exquisitely differentiated to suit the requirements of the ocular motions, and where it surrounds the sclerotic forms the outer layer of Tenon's capsule, or, in other words, the *external capsule* of the eye. It is lined by a delicate *internal capsule*, which is of a different nature, being regarded by some as the serous membrane (*i. e.*, the pericardium or pleura) of the eyeball.

The common aponeurosis of the orbit extends from one structure to another, splitting to encapsule each, but it is convenient to commence its study by distinguishing that part of it which is specially in relation to the ocular muscles.

We have already seen that the orbit contains a group of muscles which spring from the circumference of the optic foramen, and separate as they proceed forwards, so as to form a cone.

Ensheathing this *muscular cone* there is a *fascial cone*, which extends from muscle to muscle, splitting to invest each with a fibrous sheath, and sending off layers here and there to enclose lobules of fat, vessels and nerves. This cone of fascia is attached at the apex of the orbit to the periosteum round the optic foramen, and widens as it advances till it gains the orbital outlet, to be rigidly attached to the periosteum all round the margin.

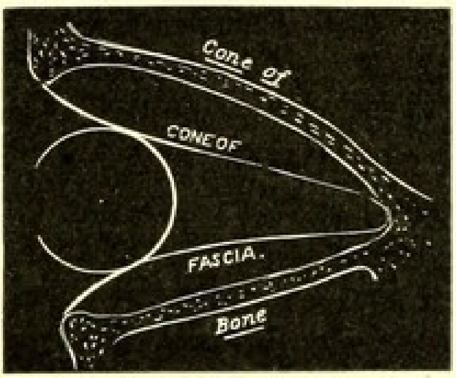

Fig. 3

There is, therefore (as shown at Fig. 3), a kind of *cone of fascia* within a *cone of bone*, with this difference between them, that while the bony cone contracts at its brim, the fascial cone expands at its brim, so that an interval exists between the two which is filled up with the peri-ocular fat, the extra-muscular fat, the lachrymal gland, etc. Fig. 3 shows very clearly how the eyeball is suspended in this cone, from above, and from all sides as well as from below ; so that the part beneath the eyeball, which partly supports it as on a hammock, receives too much credit by the name hitherto given to it, of "the suspensory ligament of the eyeball."

The fascial cone lodges the eyeball in front, and the retro-bulbar fat behind. It is divided into two compartments—an anterior one for the eyeball, and a posterior one for the retro-bulbar fat—by a hemispherical aponeurotic septum (*P. E. C.* in Fig. 4), which adapts itself to the posterior hemisphere of the eyeball. This septum is given off from the fascial cone just opposite the equator of the globe all around, and from the same line of origin springs a companion membrane (*A. E. C.*) which passes forward over the anterior hemisphere, investing it pretty closely as far as the margin of the cornea, where it becomes attached.

These two eye-investing membranes are regarded as forming one capsule, known as Tenon's external capsule. It sends prolongations backwards in the form of a sheath for the optic nerve (separated from it by the supra-vaginal lymph space) and for the various vessels and nerves which enter the eye, and though nothing more than a part of the common aponeurosis of the orbit, is endowed with remarkable elasticity.

Since on reaching the edge of each muscle the fascial cone splits into two layers, one to cover the orbital surface of the muscle and the other to cover the ocular surface, we find on studying a longitudinal section of a muscle that we have to take account of these two layers, as in Fig. 4. The deep layer (*D.*) becomes continuous at the equator of the eye (*I. C. L.*) with the posterior hemisphere of Tenon's capsule (*P. E. C.*), so that from thence forwards the deep surface of the muscle and its tendon have no fascial investment.

When we consider the orbital layer of each muscle-sheath we find the case is not so simple. As it approaches the neighborhood of the globe it thickens, and becomes more closely attached to the muscle itself, till opposite the equator the attachment reaches its maximum ; after that it quits the muscle altogether, though not until it has sent off a prolongation forward over the tendon to contribute to the anterior portion of the globe's investment (*A. E. C.*), and proceeds in the form of a thick band (*Ext. C. L.*) to the orbital margin.

**Check Ligaments.**—The thick band, just spoken of, is not a separate structure, but only a greatly-thickened strip of the anterior part of the fascial cone which we described first of all and which has a continuous attachment all around the circumference of the orbital outlet. Its principal thickened bands are, to use Tenon's words, "singularly supple and elastic," and are called the internal and external "check ligaments."

Sappey has described smooth muscular fibers in them close to their orbital attachment.

Anteriorily they are, through the periosteum, rigidly fixed to the orbit: by their posterior extremities they are attached to—

(*a*) The outer layer of the sheath of the muscle, which, it will be remembered, is part of the fascial cone described first of all;

(*b*) The muscle itself through both fibrous and muscular attachments to the belly of the muscle in that region;

(*c*) To the posterior hemisphere of the fascial investment of the globe (*P. E. C.*) by means of a crescentic thickening of the

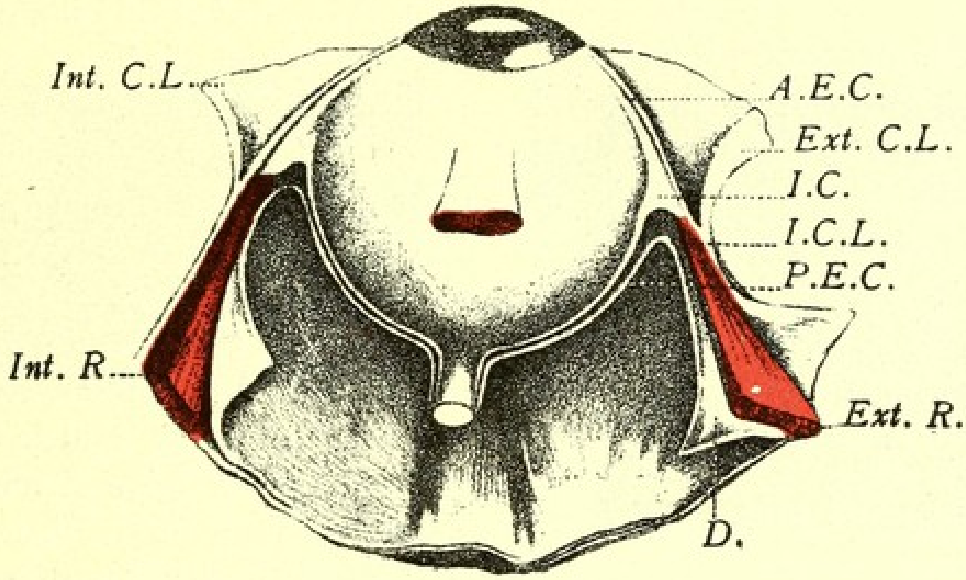


**Fig. 4**

Tenon's Fascia (from *Motais*). *Int. C. L.* and *Ext. C. L.*—Internal and External Check Ligaments. *Int. R.* and *Ext. R.*—Internal and External Recti. *A. E. C.* and *P. E. C.*—Anterior and Posterior External Capsule. *I. C. L.*—Intra-capsular Ligament, or "Collarette." *I. C.*—Internal Capsule. *D.*—Deep Layer of Muscular Sheath.

deep layer of the muscular sheath just where it is reflected (*I. C. L.*) back on the globe. The check ligament draws on the horns of this fibrous crescent (called by Lockwood the "*intra-capsular ligament*," and by Motais the "*collarette*"), past the edges of the muscle, so that some suppose it to act as a kind of pulley or stirrup over which the muscle works and which keeps it from exerting injurious pressure on the globe during its contraction.

**Uses of the Check Ligaments.**—Besides this action, it is evident that the check ligaments, by acting on the posterior hemisphere of Tenon's capsule, help to draw the eye forward (like, *e. g.*, the strings of a night cap) against the backward traction of the recti, and in this they are aided by the entire anterior portion of the fascial cone, of which they are only thickenings.

By their direct attachments to the recti, too, they moderate the power of these muscles on the eye even with respect to the muscular tone in the absence of voluntary contraction. When a muscle contracts they act very beautifully, extending in length and acting, no doubt, according to Hooke's law, "*ut tensio, sic vis*," so as to oppose greater and greater resistance to the further contraction of the muscle, like an elastic "brake." (Compare Figs. 5, 6 and 7.)

Merkel* pointed out that when a check ligament is divided, an excessive rotation of the eye is permitted, and to this Motais† has added proof that at every stage of rotation less muscular power is required to produce the same effect on the eye after division of the ligament than when it is intact, so that it is not only a *check* ligament but also a "moderating agent of the movements of the globe during the whole duration of muscular contraction."

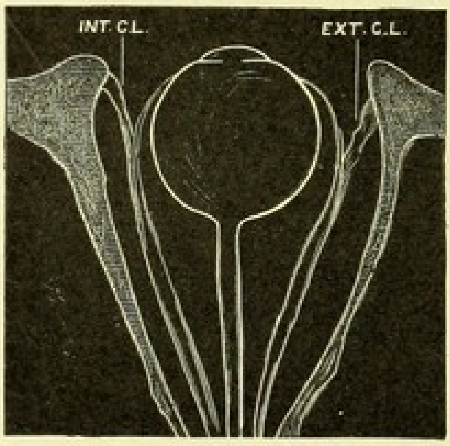


**Fig. 5**

(*Motais*) The Check Ligaments during the primary position of the eye.

My thought is that they help to slow off the movements of the eye towards their limits, so as to avoid shock to its contents by sudden arrest or by change of direction of motion. For when a continuous force acts on a moving body (unless the resistance increases proportionately) there is a constant acceleration of speed. Were the muscles to act in an unrestrained way on the eye, its motion would be far more rapid at the end than at the beginning of each movement. Owing to the provision made against this, I think that the motion rather slows off as the limits of mobility are reached, a greater and greater resistance being interposed.

Indeed, we may think of the internal and external recti as each possessing two tendons of insertion—one inextensible tendon attached to the globe, and another highly extensible tendon attached to the orbit, like the two limbs of a letter Y. When the stem of the Y, which represents the belly of the muscle, contracts, let us see what happens. At the commencement of a muscular contraction almost all the force acts on the globe, through the inextensible limb of the Y, namely, the tendon, since the extensible one (the

* Graefe und Saemisch, Band I., p. 59.

† Motais: "Anotomie de l'appareil moteur de l'œil."

check ligament) offers but little resistance, and thus the early part of the movement of the eye takes place with that velocity which is so valuable for the requirements of life ; but as the motion continues, more and more of the force is transferred from one limb of the Y to the other, till at last it nearly all acts on the rigid bone of the orbit. The eye is thus preserved from the development of excessive kinetic energy, which, it will be remembered, varies not as the speed merely, but as the square of the speed. It is also preserved from excessive traction on its coats, which might distort it ; and the limitation of its arc of mobility is determined not so much by

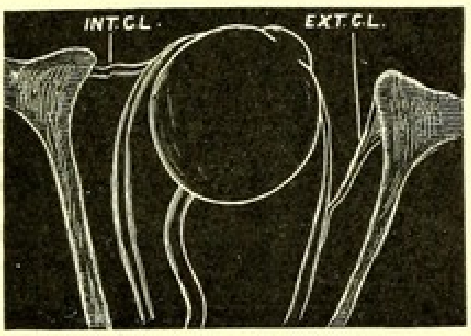


**Fig. 6**

(*Motais*) The Check Ligaments during partial contraction of the Ext. Rectus muscle, the Int. Check Ligament being in a state of maximum relaxation, and the Ext. one being somewhat stretched.

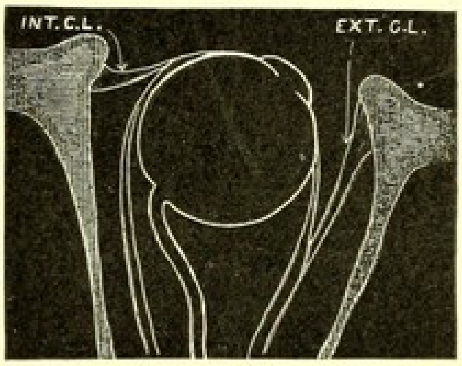


**Fig. 7**

(*Motais.*) To show how, during full contraction of the Ext. Rectus, the Ext. Check Ligament is stretched to its maximum length, and the Int. is slightly stretched also.

impediments acting against the eyeball itself as by the restraint imposed on the acting force. This is a perfect arrangement.

The maximum extensibility of a check ligament is 10 to 12 mm. (Motais), and this exactly agrees with the known shortening of a muscle which would require to produce a maximum excursion of the eye, say, of 45° or 50°.

The excursion does not cease because the eyeball itself is not capable of a more extreme rotation, nor yet because the muscle has attained its maximum contraction.

Of these two statements, the first is proved by the fact that division of the check ligament allows a super-physiological effect on the eyeball* (Merkel), and the second by the fact that the contraction of the rectus required for a maximum physiological excursion of the eye is scarcely more than a *quarter* of its length, while

* Graefe und Saemisch, Band I., 1874.

it is known that striped muscles are generally in their maximum contraction shortened by *half* their length. Motais pointed this out.

**Internal Capsule of the Globe.**—This thin, transparent membrane, which is represented in Figs. 8 and 12, is lined on its sclerotic side by endothelial cells, and envelopes the whole eye as far forward as the insertions of the tendons.

By its outer surface, it is attached to the more resistant outer capsule. Underneath the tendons of the muscles, however, it runs

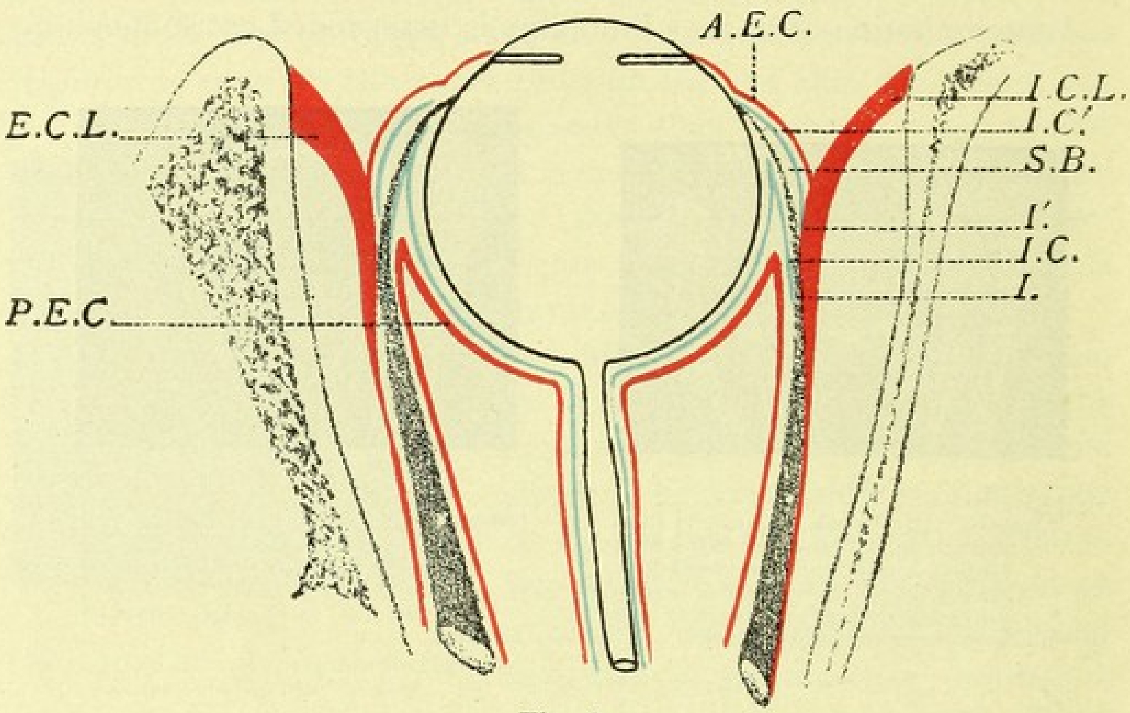


**Fig. 8**

A horizontal section of the Globe and its Membranes (after *Motais*). *E. C. L.* and *I. C. L.*—External and Internal Check Ligaments. *A. E. C.* and *P. E. C.*—Anterior and Posterior portions of the External Capsule. *I.*, *I'.*, *I. C.*, *I. C'.*—Reflection of Internal Capsule on the tendon. *S. B.*—Serous Bursa.

forwards to the insertion of the tendon, and is then reflected backwards on to the under surface (*I. C.*) of the tendon and muscle, as far as the collarette, and mounting round its edges to gain its upper surface, it there forms a serous bursa (*S. B.*) which is elongated antero-posteriorly, and partitioned inside by filaments of cellular tissue.

Between the inner capsule and the sclerotic is Tenon's space, which is really a finely-divided multilocular lymph sac. It is in principle the subarachnoid space of the eye, since the inner capsule represents the arachnoid mater, and the outer capsule the dura mater, of the globe. These peri-ocular membranes are indeed continuous with the arachnoid and dural envelopes of the brain, though the continuity cannot always be demonstrated. There are thus two sheaths on the optic nerve, of which the inner is continuous anteriorly with the internal capsule of the globe and posteriorly with the arachnoid of the brain, and this sheath can be distended by injection from the sub-arachnoid space; the outer sheath of the optic nerve is continuous anteriorly with Tenon's outer capsule of the globe, and posteriorly with the dura mater of the brain.

Injections practiced into Tenon's space, by Schwalbe and others, show that it communicates with the supra-chorioidal space, through the openings of the sclerotic which transmit the vasa vorticosa.* In the operation for strabismus, it is customary to pick up Tenon's capsule in the forceps, together with the conjunctiva, and as soon as the scissors have entered within the capsule their points move freely within the space, for the fine filamentary and areolar tissue which partially occupies it ("tunica adventitia oculi") offers almost no resistance to their movement. Hemorrhage may take place into this space from wounding one of the muscular arteries and may sometimes envelope and protrude the whole of the posterior two-thirds of the globe.

In certain conditions of health the presence of liquid in Tenon's space can be demonstrated by pressing the eyelid against the globe from the equator forwards. Tenon's space contains scarcely any free lymph, or its pressure would be noticed during the operation for strabismus.

The numerous delicate fibrous connections which exist between the inner capsule and the sclerotic, remind one, though much finer, of the loose cellular tissue between the occipito-frontalis tendon and the peri-cranium, and no doubt play a part in the motions of the eyes, which is very similar to that which the sub-tendinous tissue plays during contraction of the occipito-frontalis.

**Movements of Tenon's Capsule.**—From what we have now studied of Tenon's capsule, we may see at once that it differs entirely from such a bony socket as that of the acetabulum, since being fixed to the globe near the cornea, and loosely so at the optic nerve, it accompanies the motions of the globe to a large extent. Not entirely, however, except just in front, for its elasticity allows it to "give" in some places more than in others.

Motais has shown by careful experiments that the fatty tissue which immediately surrounds the globe, also to a large extent accompanies its movements, and every succeeding layer moves less

*One observer has denied that Tenon's space is a lymph space, on the ground that he could not find an open space at all; but this is no proof, since the same might be said of the lymph spaces in ordinary areolar tissue.

than the one within it. He suggests that the real socket is formed by the inside of the eyelids, since they move least in accordance with its motions ; but the fact of the matter is that the eye is an organ *sui generis*, and must not too closely be compared to a bony joint. When we remember the elastic nature of its connections, it strikes us as exceedingly well poised that its center of motion should remain so stationary while acted on by such various muscles.

**Why the External Check Ligament Should be Thicker and More Powerful** than any other, is not at first sight evident, but it may possibly be explained by the fact that the ocular muscles *all* rise nearer the median plane than they are inserted, and unless some special provision existed, the eyeball as a whole might be drawn too much inwards. As it is, however, it is poised in the aponeurotic funnel, or fascial cone which extends from the margin to the apex of the orbit, and the outer part of this funnel between the globe and the orbit is endowed with greater strength than any other portion.

**Bearing of the Check Ligaments on Tenotomy.**—Motais called attention to the way in which the check ligaments affect the result obtained by a tenotomy, and the following are almost his own words :

"The tendon, say, of the internal rectus, is cut. Immediately, by its tonicity alone, the muscle retires backwards, drawing the tendon with it, it may be, let us say, 5 mm.

"The check ligament adhering on one hand to the muscle, and fastened on the other hand to the orbit, can only lend itself to the retreat of the muscle by elongating 5 millimeters (compare Fig 9).

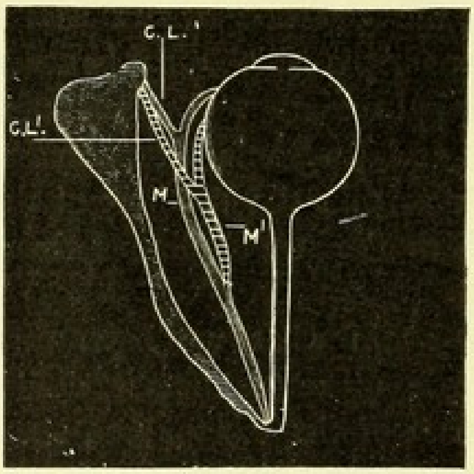


**Fig. 9**

(*Motais.*) To show the effect of Tenotomy, *M* being the Muscle before, and *M'* after, the operation. *C L* is the Check Ligament before operation, and *C L'* the same elongated after operation by recession of the muscle.

"Henceforth, therefore, in consequence of the new anatomical conditions introduced by the tenotomy, the check ligament, *during muscular repose*, will already be experiencing an elongation of 5 mm. But we know that its maximum elongation is not greater than 10 to 12 mm. It has, consequently, only 5 to 7 mm. of further lengthening at its disposal, during muscular contraction. There results a proportionate insufficiency of adduction, a diminution in the arc of rotation.

"But that is not all. The tension of the ligament, feeble at the commencement of elongation, gradually increases. The more it elongates, the greater becomes its tension, the more energetic becomes its resistance to muscular action.

"If the tenotomy has already produced a lengthening of the ligament 5 mm., the muscle from the beginning of its contraction will be restrained by a ligament already considerably stretched. Its contractile power will, by just so much, be lessened.

"Therefore, we shall have at once from the ligament, diminution of the *extent* and of the *energy* of the muscular action. In *advancements*, the same phenomena occur in the opposite sense.

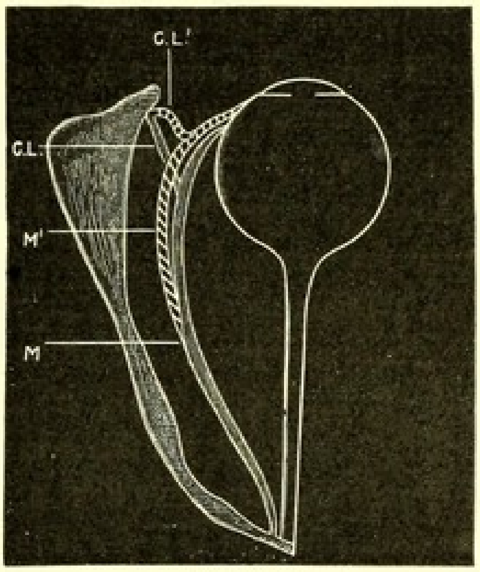


**Fig. 10**

(*Motais.*) To show the effect of Advancement, *M* being the Muscle before, and *M'* after, the operation. *C L* is the Check Ligament before the operation, and *C L'* the same relaxed after operation.

"The ligament is advanced at the same time as the muscle. In its new position its two points of orbital and muscular insertion being brought nearer to each other, it is of course relaxed (Fig. 10).

"If the advancement be 3 mm. the ligament will not reach its maximum extension till 3 mm. later, if I may so express it.

"Further, the ligament, being completely relaxed at the beginning of contraction, during the first three millimeters will be slack to resist the muscular contraction. We shall have, therefore, at the same time, an increase of the *extent* and of the *energy* of the muscular action."*

All the muscles of the globe seem to be provided with something answering to check ligaments. The following account of them is taken chiefly from Motais :

**External Check Ligament** (Aileron ligamenteux externe).—This is shown as *Ext. C. L.* in Fig. 4, and *E. C. L.* in Fig. 8, and is a thick, grayish-white band, which leaves the external rectus

*"L'appareil moteur de l'œil" (1887), pp. 147 to 150.

muscle near its anterior extremity, proceeding forwards and slightly outwards, continuing in very nearly the same direction as the belly of the muscle, to the outer margin of the orbit.

Its mean breadth is 7 or 8 millimeters ; its length from the farthest back point of its adherence to the muscle is from 18 to 20 millimeters. Its greatest thickness, which varies between 3 and 6 millimeters, is at its orbital insertion. These are the figures given by Motais. He adds that it is not formed of a compact bundle, but of a great number of compact fascicles, some of which are very thin. In its posterior two-thirds it is composed of a mixture of fibrous and elastic tissue : in its anterior third M. Sappy discovered numerous smooth muscular fibres.

The sheath of the external rectus muscle, thin and cellular at the back of the orbit, becomes more and more compact as we trace it forwards along its belly. In its posterior two-thirds it is loosely attached to the muscle. But, all of a sudden, about 20 millimeters from the sclerotic insertion of the muscle, it thickens considerably and plants itself on the muscle so firmly that in detaching it we always tear some of the muscular fibres. These adhesions extend forwards 5 or 6 millimeters. The muscle then changes its direction to incline inwards towards its sclerotic insertion. The check ligament, instead of following the curve of the muscle, abandons it, at an angle which varies according to the position of the globe, to reach the margin of the orbit, where its insertion has a breadth of 7 or 8 millimeters, and a depth of 3 to 6 millimeters. The upper border of the ligament is reinforced by a band from the superior check ligament.*

**Internal Check Ligament** (Aileron ligamenteux interne).—This is shown as *Int. C. L.* in Fig. 4, and *I. C. L.* in Fig. 8, and is broader, but thinner, than the external check ligament. It has no interstices like the latter. Its color is a yellowish gray, and near the orbital margin a pale red.

Though the prominence which forms it is much less differentiated from the neighboring parts of the aponeurosis than that of the external ligament, it can easily be distinguished when it is put on the stretch by drawing on the internal rectus muscle behind.

Its breadth is from 8 to 10 millimeters. Its length from the posterior extremity of its attachment to the muscle to its bony insertion

* Panas says that between this check ligament and the corresponding palpebral ligament, and the sub-conjunctival fascia, there exists a space containing fat, and the small accessory lachrymal gland, which, he says, we constantly discover in the operation of canthoplasty.

"along the line of the crista lacrimalis posterior and the wall of the orbit just posterior to this line" (Howe), is from 15 to 18 millimeters. Its thickness is from 1 to 1½ millimeters, near to its bony insertion. In very fatty orbits, if the muscles are atrophied, it is the least distinct of all the check ligaments. Panas says that it is fused (by an expansion which covers Horner's muscle) with the internal palpebral

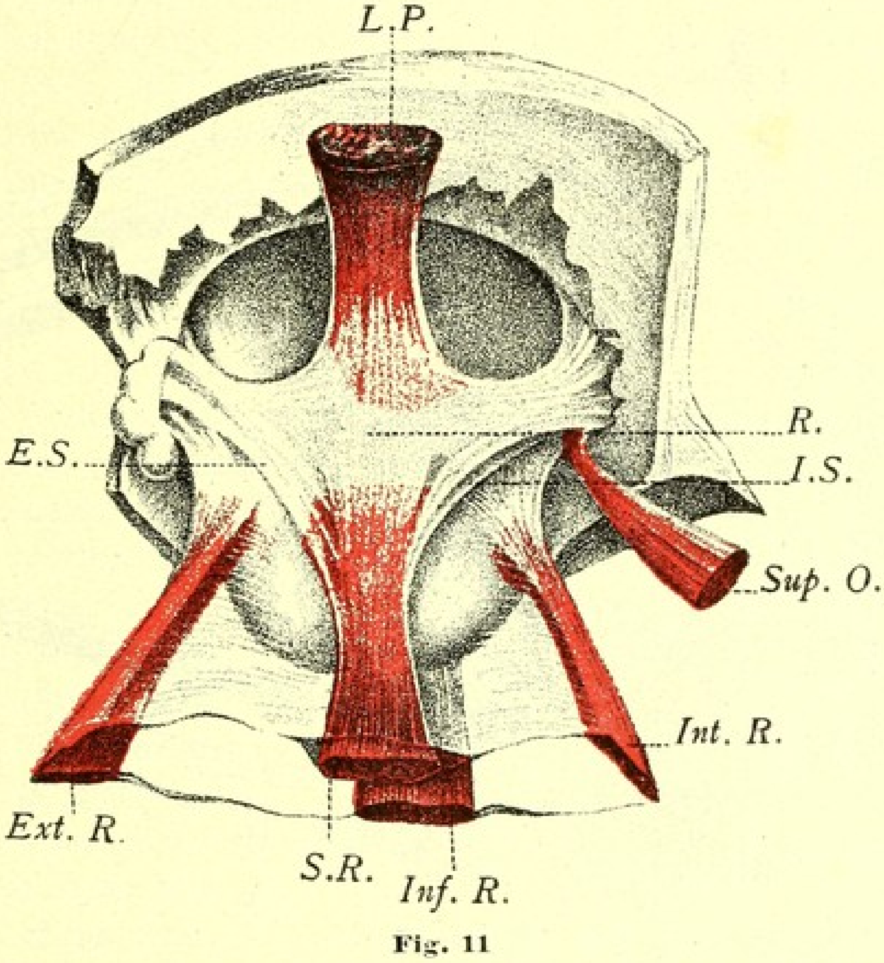


**Fig. 11**

(After *Motais.*) View from above, the Levator Palpebræ (*L. P.*) being reflected forwards, to show how the fascia is reflected from its under surface, at *R*, on to the upper surface of the Superior Rectus (*S. R.*). Compare *R* in Fig. 12. *E. S.* and *I. S.*—External and Internal Superior Check Ligaments.

ligament, so that when the right internal rectus contracts, it draws back the inner commissure of the lids, the semilunar membrane and the caruncle, at the same time that it compresses the lachrymal sac.

**Superior Check Ligaments.**—These are two. Owing to the broad tendon of the levator palpebræ being interposed between the superior rectus and the orbital margin, the superior check ligaments from the superior rectus cannot reach their orbital insertions except by passing each border of the levator palpebræ tendon. Were there a single median check ligament, it would have to pierce this intervening tendon to reach the bone (see Fig. 11).

That this affords an explanation for there being two superior check ligaments is shown by the fact, noted by Motais, that those vertebrata which possess a levator palpebræ have these ligaments double, whereas those which possess no levator have a single median ligament.

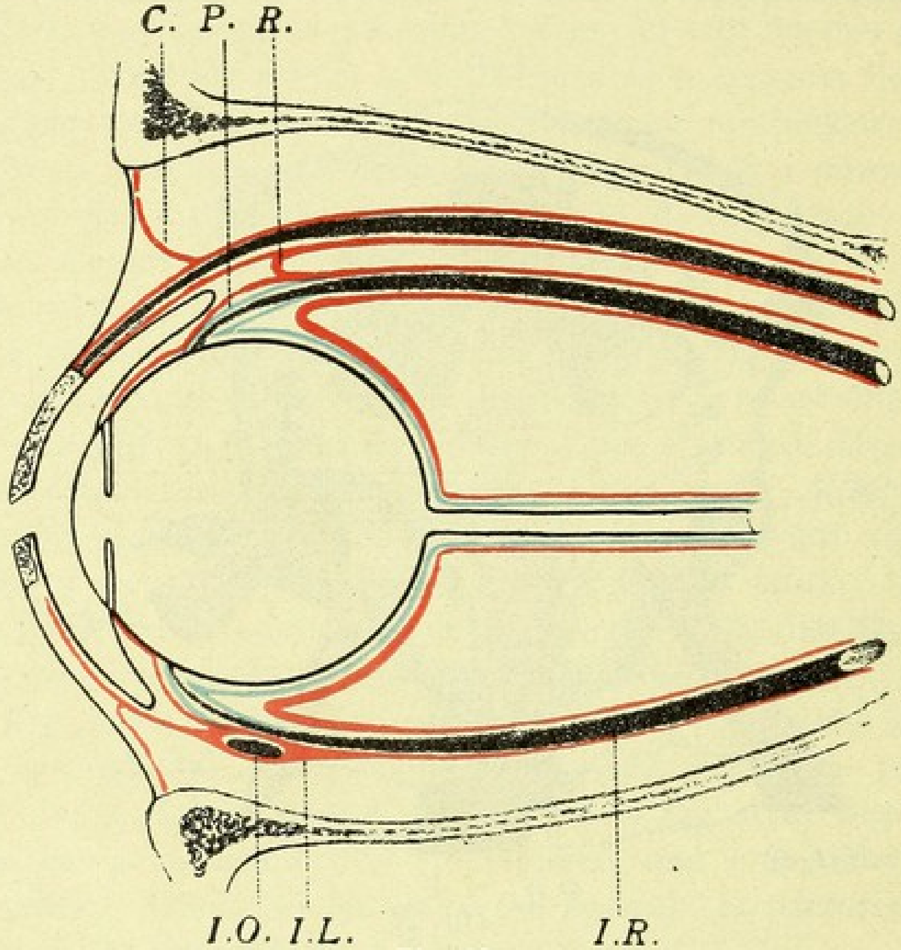


**Fig. 12**

(After *Motais*). Vertical longitudinal section of Eyeball and adnexa. *R.*—Reflexion of fascia from the under surface of the Levator Palpebræ on to the upper surface of the Superior Rectus. *C.*—Part of the funnel-shaped expansion proceeding to the margin of the orbit. *P.*—Expansion to contribute to the anterior part of the capsule. *I. R.*—Inferior Rectus. *I. O.*—Inferior Oblique. *I. L.*—Check Ligament of the Inferior Rectus, embracing the Inferior Oblique.

He describes the *internal superior check ligament* (*I. S.*) as a fibrous cord which leaves the inner border of the superior rectus muscle, applies itself to the tendon sheath of the superior oblique muscle, and is inserted with it at the trochlea. Sometimes a few muscular fibres run into it, and in any case it is intimately adherent to the muscle, just as the internal and external check ligaments are to theirs.

*The external superior check ligament* (*E. S.*) is a more flattened band than the preceding cord, and divides into two, one portion joining the upper border of the external check ligament and the other portion reaching the orbital margin midway between this and the outer extremity of the tendon of the levator palpebræ.

**The Inferior Check Ligaments** are also two, but are a little difficult to understand.

That of the inferior rectus leaves the sheath and belly of the inferior rectus at the point where that muscle begins to curve round the globe, adhering intimately to the muscle and to its thickened sheath, for a length of 5 or 6 millimeters (see *I. L.* in Fig. 12).

It proceeds to the middle part of the inferior oblique muscle (*I. O.*), splitting into two so as to embrace it, as shown in the figure, establishing thus a strong connection between these two muscles.

Its appearance is whiter and its structure more exclusively fibrous than that of the other check ligaments, so that, with a moderate thickness, it is as resistant as the external check ligament itself (Motais). It obtains no direct insertion into the margin of the orbit, but only through a loop, of which one limb is formed by the inferior oblique muscle and the other limb by the check ligament of that same muscle. This is shown in Fig. 13. For this reason it is that Fig. 12 looks as if the check ligament of the inferior rectus had no insertion except its slender offshoot to the eyelid, which, however, accounts for the eyelid being drawn down during contraction of the inferior rectus.

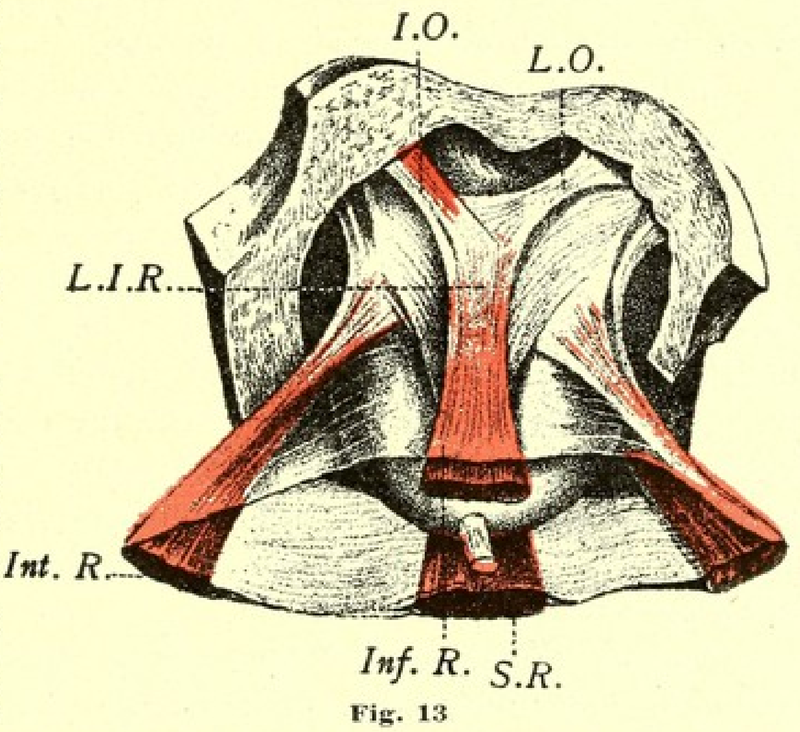


**Fig. 13**

(Motais.) View of the *under* surface of the Eyeball, the floor of the orbit being removed to show the Check Ligament (*L. O.*) of the Inferior Oblique muscle (*I. O.*). These form two limbs of a Y, the stem of which is the Check Ligament (*L. I. R.*) of the Inferior Rectus (*Inf. R.*), seen to embrace the Inferior Oblique. *Int. R.*—Internal Rectus. *S. R.*—Superior Rectus.

We have seen that it embraces the inferior oblique muscle, in Figs. 12 and 13. From the point where it does so, springs the structure we have next to consider.

**The Check Ligament of the Inferior Oblique.**—This fibrous bundle (*L. O.* in Fig. 11), derived in part from the fibres of the check ligament of the inferior rectus, in part from the sheath of the inferior oblique muscle, leaves the anterior border of the inferior oblique about 8 or 10 millimeters from its orbital origin, and from thence courses obliquely outwards and forwards. It forms an obtuse angle of about 120° with the check ligament of the inferior rectus muscle. With the inferior oblique it forms an angle of about 110°. Its length is from 10 to 12 millimeters, and it is inserted into the lower outer angle of the orbit, 4 or 5 millimeters behind the orbital margin, about midway between the external check ligament and the origin of the inferior oblique.

This bundle is the most pearly looking, the most purely fibrous of all the aponeurotic lamellæ of the orbit.

Its breadth varies at different parts of its course : in the middle, 2 or 3 millimeters ; at its muscular insertion, 7 or 8 millimeters ; at its bony insertion, 5 or 6 millimeters. It presents, therefore, the shape of two triangles united by their apices.

Motais thinks it acts not only as a moderator for the inferior oblique, but also as a "pulley of reflection."* Together with the inferior oblique itself, it forms a kind of musculo-aponeurotic loop, the two ends of which are inserted near the orbital margin, one at the outer angle, the other at the inner angle. And the check ligament of the inferior rectus muscle embraces the middle portion of this loop, so that when the inferior rectus begins to contract, its check ligament stresses the loop.

The check ligament of the inferior rectus has therefore for its orbital insertions the tendon of the inferior oblique muscle, and the check ligament of the same muscle like the two limbs of a Y.

**The Connection of the Levator Palpebrae Muscle with the Superior Rectus** deserves a passing notice, since these muscles work so uniformly together.

From the upper surface of the sheath of the superior rectus, near its inner border, and along its whole length from the apex of the orbit to the equator of the eyeball, is given off a sheet of fibro-cellular tissue, which reaches the under surface of the levator, and splits into two to enclose that muscle, thus providing it with a sheath.

* By this he must mean that when the muscle contracts, the ligament slightly bends the muscle by drawing its middle part outwards, so as to make its traction on the eye a little less oblique.

On reaching the equator, however, the upper surface of the sheath of the superior rectus is reflected (*R* in Fig. 12) as a whole on to the under surface of the levator, describing a strong curve, with concavity backwards, in its passage from one muscle to the other. A prolongation (*P*), however, still continues to cover the outer or upper surface of the tendon of the superior rectus, and forms, in fact, part of the anterior hemisphere of the external capsule of the eye continuous with *A E C* in Fig. 4. From the upper surface of the levator is given off a facial layer (*C*), which goes to the orbital margin, and forms part of that facial cone in the orbit which we commenced this whole subject by describing. Notice, too, that the nerve for the levator penetrates the superior rectus.

## CHAPTER II

# The Ocular Motions

A universally mobile body is capable of no fewer than six independent motions, which are called "degrees of freedom." It can be translated as a whole in any three directions at right angles to each other, or be rotated about any three axes at right angles to each other.

**Translations of the Globe.**—If we regard the head as fixed, and confine ourselves to the study of the voluntary motions of the eyeball, we shall find it *approximately* true that translation of the globe is forbidden in virtue of its attachments to the orbit.

Were we to investigate this statement very strictly, we should not, however, find it rigidly true, since the center of motion lies a little farther back than the geometrical center of the eyeball, in consequence of which the globe is slightly translated in whatever direction the eye is made to turn. On looking to the right, the globe is translated slightly to the right; on looking to the left, to the left, and so on. In the maximum excursions of the eye, this translation is probably not less than 1, or greater than 2 millimeters.

**Center of Motion.**—The distance between the mid-point of the optic axis and the center of rotation is given by Donders and Mauthner as follows:

| Refraction | Donders | Mauthner |
|---|---|---|
| In Emmetropia . . . . . . | 1.77 mm. | 1.24 mm. |
| " Myopia . . . . . . . . . | 1.75 mm. | 1.82 mm. |
| " Hypermetropia . . . . . | 2.17 mm. | 1.47 mm. |

Since, except to the trifling extent just noticed, translation is denied to the eye, we may now turn our attention to its rotations.

**Rotations.**—A body deprived of translation might still be able to rotate, and that about three axes at right angles to each other. Rotations about all other axes are resolvable into rotations about two or more of these, from which it follows that a body which enjoys three degrees of rotational freedom can rotate about as many diameters as are conceivable.

We have, therefore, next to inquire whether the eyeball retains this full rotational freedom.

**One Voluntary Rotation Denied.**—Actual experiment has shown, what we could not have otherwise proved, that one degree of freedom is lost in all voluntary parallel movements of the eyes which start from the straight forward position.*

The degree of freedom lost is that of rotating about the fore-and-aft axis (considered as fixed in the head), while the two freedoms retained are those of rotation about the vertical axis, and about the transverse axis (both considered as fixed in the head).

**Listing's Plane.**—Simultaneous rotations about the vertical and transverse axes can be variously compounded into rotations about any intermediate axis. This is equivalent to saying that they are limited to rotations about all conceivable diameters in one plane, namely, that plane in which the vertical and transverse axes lie, and which it is convenient to call "Listing's plane," since this degree of constraint was discovered by Listing.

*Listing's plane* passes through the center of motion of the eyes, and is a vertical transverse plane (corresponding to a coronal section) fixed in the head, and perpendicular to the fore-and-aft axis, about which rotation is denied.†

When the head is held erect and the eyes look straight forward at a very distant object on the horizon, they are generally said to be in their "primary position," and though we shall have to quote a truer definition later on, we may for the present accept this simple one, in order to say that however many and complex the motions of an eye may be in glancing from point to point, the *ultimate* result of them all is equivalent to a single rotation of the globe about some one axis in Listing's plane, provided the eye has started from the primary position.‡

**Torsion.**—By *torsion* we mean rotation of the eyeball about its own fixation line.§

* Latent Torsion, discussed in Chapter XIII., is not voluntary.

† In the "primary position" of the eye, Listing's plane is practically identical with the "equatorial plane" of the eye, but it must not be identified with it, since the latter moves with the eye, whereas Listing's plane does not.

‡ It will be seen that I have guarded myself from stating that rotations from one *secondary* position to another are about axes in Listing's plane. They are not. Helmholtz has correctly shown in what plane they lie.

§ "We will call *torsions* rotations of the eye about the line of fixation" (Helmholtz).

Let us remember that there are two fore-and-aft axes we have to consider, one of which is fixed in the head and which we have already treated, and another proper to the eyeball itself and moving with it, so as, indeed, to be for all practical purposes regarded as identical with the fixation line.

**Secondary Torsion.**—When the eyeball (starting from the primary position) rotates either vertically upwards or downwards, or horizontally to either side, its motions are called "cardinal motions," and are not accompanied by torsion. But when the eyeball looks obliquely, in any intermediate direction, two cardinal motions are compounded together. Every motion of an eye from the primary into an oblique position is accompanied by torsion as an essential component of the motion.

**Donders' Law.**—Donders' observed that whatever position the eyeball may take, there belongs to that position a definite amount of torsion which remains the same no matter how often the eye may return to that position, and however many motions it may make in arriving at it.

To quote his own words: "For any determinate position of the line of fixation with respect to the head, thereto corresponds a determinate and invariable angle of torsion, a value independent of the volition of the observer, independent also of the manner in which the line of fixation has been brought into the considered position."

The same law has been put more concisely by Helmholtz (and at the same time amplified) in the words: "The wheel-movement of each eye is, with parallel fixation lines, a function only of the elevation angle, and of the lateral deflection angle."*

**Listing's Law.**—The law of Listing goes a step further than that of Donders, and is as follows: "*When the line of fixation passes from its primary to any other position, the angle of torsion of the eye in this second position is the same as if the eye had arrived at this position by turning about a fixed axis perpendicular to the first and second positions of the line of fixation.*"

This simply means that when the eye starts from the primary position and glances towards an object situated obliquely (*e. g.*, up and to the right), the line of fixation takes the shortest possible cut to its new direction, and in so doing must necessarily sweep along a plane common to its original and its new position. To

* Helmholtz's "Optique Physiologique," page 602.

permit it to do this the eyeball must rotate around an axis perpendicular to this plane and, therefore, perpendicular to the line of fixation throughout the whole of its motion. Since the shortest cut requires the briefest time to traverse, it is manifest that this law is essential to the perfection of the ocular movements where rapidity is so advantageous. The exquisiteness of this design is apparent when one considers that no fewer than three muscles are concerned in every oblique motion of the globe, not one of which, acting individually, would rotate the eye about the required diameter.

**Reasons for Listing's Law.**—I think a little consideration will show that the arrangement on which Listing's law is based is that which entails the *absolute minimum of motion* (calculated as the sum of the motions of all the particles of the eye), so that (*a*) the momentum of the ocular contents is the least possible ; (*b*) the time is the shortest ; (*c*) the work done the least, and (*d*) the lowest amount of dangerous "kinetic energy" is developed. A second, more important, reason is, that by no other equally efficient arrangement could the law of Donders be possible, since the torsion belonging to each position of the eye would not be a constant quantity, and this would throw the brain out in its calculations.

**Proof of Listing's Law.**—The truth of this law has been confirmed (within the sphere in which it holds good, namely, that of the *parallel* motions of the eyes) by every observer that has undertaken to test it by actual observation.

It is desirable to study the motions of the eyes before commencing to consider the muscles by means of which they are brought about. This will save us from falling into errors from failure to distinguish between motions actually observed and those which our preconceived notions of the oblique muscles might make us think ought to take place.

A most delicate means of following the *parallel* movements of the eyes, attributed to Rente, is afforded by the experimental use of "after-images." The following mode of inquiry thereby is that most to be recommended :

Let the experimenter affix vertically a scarlet ribbon, two or three feet long, to a gray wall, with the center of the ribbon at the same height as his own eye, when seated at some distance therefrom, and with his head erect and squarely facing the wall let him gaze at the center of the ribbon for a minute or two. On now raising his gaze directly upwards, while keeping his head immovable, a faint after-image will move upwards with the eyes, but will remain strictly vertical. On lowering his gaze, the after-image will sink simultaneously but still remain vertical. If, however, after raising his gaze he were to turn his eyes to the right, the after-image would no longer remain vertical, but would slope to the right; on looking up to the left, it would slope to the left; on looking down to the right its upper end would again slope to the left, and on looking down to the left its upper end would slope to the right.

We might conclude from this that when the eyes occupy oblique positions they experience torsion equal to that of the after-image. But since those parts of the wall upon which the image falls in these positions are not perpendicular to the line of sight, the slope is exaggerated and the proof is not complete.

To vary the experiment, commence again, but with the head rotated considerably to the left and kept immovably so. Now, after gazing at the ribbon, run the eyes up the wall immediately above it, when the image will appear to become more and more twisted to the right the higher it is raised. This proves infallibly that torsion does take place on looking up and to the right, though the amount is less than the previous experiment would have led us to suppose. Similar experiments could be made for the other oblique positions of the head, which show that torsion to the right occurs on looking upwards and to the right, or downwards and to the left. On the contrary, torsion to the left occurs on looking upwards and to the left, or downwards and to the right.

Even this experiment, however, though it correctly indicates the presence of torsion and the true sense in which it occurs, does not enable us to measure it exactly, because the after-image is projected on a plane which is not perpendicular to the visual line in the secondary position. To rectify this, let a gray drawing board be suspended near the ceiling, directly above the scarlet ribbon, and be provided (according to a method of Le Conte's) with a large knitting needle projected perpendicularly from its center. Now make the drawing board lean forward, like a picture, until this needle is seen "end on" by the experimenter. On looking at the needle, the after-image is projected on to the board in a manner which represents the exact torsion of the eye. It can, if we like, be measured by a long wire so attached by its middle to the foot of the knitting needle as to rotate against the board to any required angle. If this wire be inclined by an assistant till it exactly coincides with the after-image, its deflection from the vertical exactly measures the torsion of the eye.

Now let him place the ribbon horizontally on the wall, and holding the head erect as at first, with face square to the wall, gaze at it steadily, and then move the eyes horizontally to the right. The image will now, in most cases, appear slightly tilted, with its right-hand end dipping. On turning the eyes to the left, the after-image will appear tilted in the opposite direction, the left-hand end extremely dipping.

If the face be turned somewhat downwards, the tilting of the image, on looking to the right or the left, will be greatly increased; while, on the other hand, if the face be raised towards the ceiling, the sense of the tilt will be reversed: on looking to the right the left-hand end dipping and on looking to the left the right-hand end. This fully confirms the results of the previous experiment and shows that whether we study the vertical meridian of the retina or the horizontal meridian, torsion takes place in the directions indicated.

If, however, the head be thrown only slightly backwards, a position is gained from which, when the eyes look to the right and left, the image no longer tilts, but remains strictly horizontal. The eyes while looking at the center of the ribbon are now said to be in their "primary position," which is defined *physiologically* as that from which motions of the eyes in directly vertical or directly horizontal directions are unaccompanied by torsion. On glancing, however, in oblique directions therefrom, torsion occurs.*

After providing the head of the experimenter with some means of fixing it with the exact amount of backward tilt, which brings the eyes into their primary position, the ribbon may be fixed obliquely on the wall, at an angle of, say, 45°, or any other. Whatever the angle may be, on turning the eyes in the direction indicated by the length of the ribbon, the after-image will be found to remain in a straight line with the ribbon in all parts of its course. This proves that parallel movements of the eyes from their primary position, in no matter what direction, take place as if about axes at right angles to each line of fixation while in the primary position.

The experimenter may, if he please, reach any point on the wall by a circuitous or even spiral route, but he will always find, at the end, that the after-image occupies exactly the same position as

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*Strictly speaking, the ribbon should be at an infinite distance for the definition to be true, since only then would the visual lines be parallel.

if the eyes had been moved to that position directly from the primary position.

By experiments of this kind, Donders arrived at his discovery of the law that "to every position of the fixation line with reference to the head belongs a definite and unchangeable value of torsion."

On this law of Donders, everything else rests. The laws of Listing and Helmholtz, to be described shortly, are necessary corollories.

Listing's law *relates* only to those parallel movements of the eyes which have the primary position for their point of departure, and states that the position of the eye in any secondary position is what it would gain by a rotation from the primary position about a fixed axis perpendicular to the primary and secondary positions of the fixation line. All axes of this kind must lie in one plane, viz., that which is perpendicular to the fixation line in its primary position, and which has been called, in consequence, Listing's plane.

Suffice to say that any linear after-image, which possesses, during the primary position of the eye, a given obliquity, when projected on a gray wall facing the observer, preserves the same obliquity inviolate whenever the eye glances in the direction indicated by the length of the false image, or in a direction perpendicular to its length.*

Though all observers are agreed as to the truth of Listing's law, all are not, however, agreed as to the conclusions to be drawn from it.

**Agreement of Helmholtz and Donders.**—A good deal of discussion has been made recently about the discrepancy which has been stated in America to exist between the laws of false torsion formulated by Helmholtz and those laid down by Donders.

There can be no question that their statements, as they read, look diametrically opposed to each other.

And yet a careful study of Helmholtz will show that he has chosen a different definition and index of torsion, so that his statements do not really contradict those of Donders, but perfectly agree, as indeed we could only have expected.

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*It is true that when the eye glances in oblique directions other than these, the after-image does appear to have its degree of obliquity altered, but this is fully explained in every case by the fact that it is projected on a flat surface which does not (in that part of it) face the observer, and the apparent discrepancies, when properly analyzed, only confirm the law.

Let us look at them in the following parallel columns :

| Helmholtz. | Donders. |
| --- | --- |
| "When the plane of fixation is directed *upwards*, lateral displacements to the *right* make the eye turn to the **left**; | "On the diagonal fixation *upwards* and to the *right*, the vertical meridians of both eyes suffer a parallel inclination to the **right.**" |
| and displacements to the *left* make the eye turn to the **right.**" | "On diagonal fixation *upwards* and to the *left*, the vertical meridians of both eyes suffer a parallel inclination to the **left.**" |
| "When the plane of fixation is *lowered*, lateral displacements to the *right* are accompanied by torsion to the **right** | "On diagonal fixation *downwards* and to the *right*, the vertical meridians of both eyes suffer a parallel inclination to the **left.**" |
| and *vice versa*." | "On diagonal fixation *downwards* and to the *left*, the vertical meridians of both eyes suffer a parallel inclination to the **right.**" |

**Helmholtz's Plane of Reference.**—The "plane of reference" adopted by Helmholtz is the "visual plane," by which he means the plane common to the two visual axes and to the line which joins the centers of motion of the two eyes. When the visual axes are elevated or depressed, the visual plane is elevated or depressed with them.

In the primary position of the eyes, the visual plane passes through the horizontal meridian of the retina, which Helmholtz calls the "retinal horizon." In all the cardinal motions of the eyes, which, it will be remembered, are motions from the primary position directly upwards, downwards, to right and to left, the retinal horizon lies rigorously in the visual plane ; but in oblique motions it becomes more and more inclined to the visual plane, in the sense stated by Helmholtz in the first of the above parallel columns.

**Donders' Plane of Reference.**—I do not know what plane of reference Donders selected, but (since the one which I have selected gives the same results) probably the same as that which

I have adopted in what follows, namely, a movable, ever-vertical plane, passing through the line of fixation and moving with it.

**No Torsion with Reference to the Median Plane.**—Were we to estimate torsion by reference to the median plane of the head, or any plane parallel to it, we would have to conclude there is no torsion at all, for, thus tested, the vertical meridian of the cornea would be torted in one direction and the horizontal meridian to an equal amount in the opposite direction.

Indeed, it stands to reason that motion about any axis in Listing's plane cannot have a component about a line perpendicular to that plane.

The nature of false torsion depends entirely upon the point of view from which we observe it.

**Index of Torsion.**—Since the eye is an optical instrument, I think the index of torsion should be an optical one, and, to my mind, the best plan is to imagine the point of fixation, or, in other words, the object looked at, to be an intelligent being, able to tell us what amount of torsion exists from his point of view. The torsion would thus be measured by the angle between the originally vertical meridian of the retina (*i. e.*, the meridian which was vertical in the primary position of the eye) and the vertical plane passing through the line of fixation.

When calculated in this way, the rules of false torsion agree exactly with those of Donders, and therefore with all the text-books which have followed him.

Let us give the name of Dextrotorsion to that which takes place when the upper end of the vertical diameter of the eyeball is tilted to the patient's right, and Lævotorsion to similar tilting to the left. When we look upwards and to the right or downwards and to the left, there is dextrotorsion. Conversely, when we look upwards and to the left or downwards and to the right, there is lævotorsion. In fact, the paths of the after-images trace out a figure shaped like a *sheaf of wheat.*

**Torsion Calculator.**—I have constructed a simple little model, which, though difficult to describe on paper, makes it very easy to demonstrate the true nature of secondary torsion and even to indicate automatically its amount in degrees for any oblique motion whatever of an eye.

In its home-made form it consists of a circular piece of cardboard (shown in No. 1 of Fig. 14), with a vertical diameter *V V*

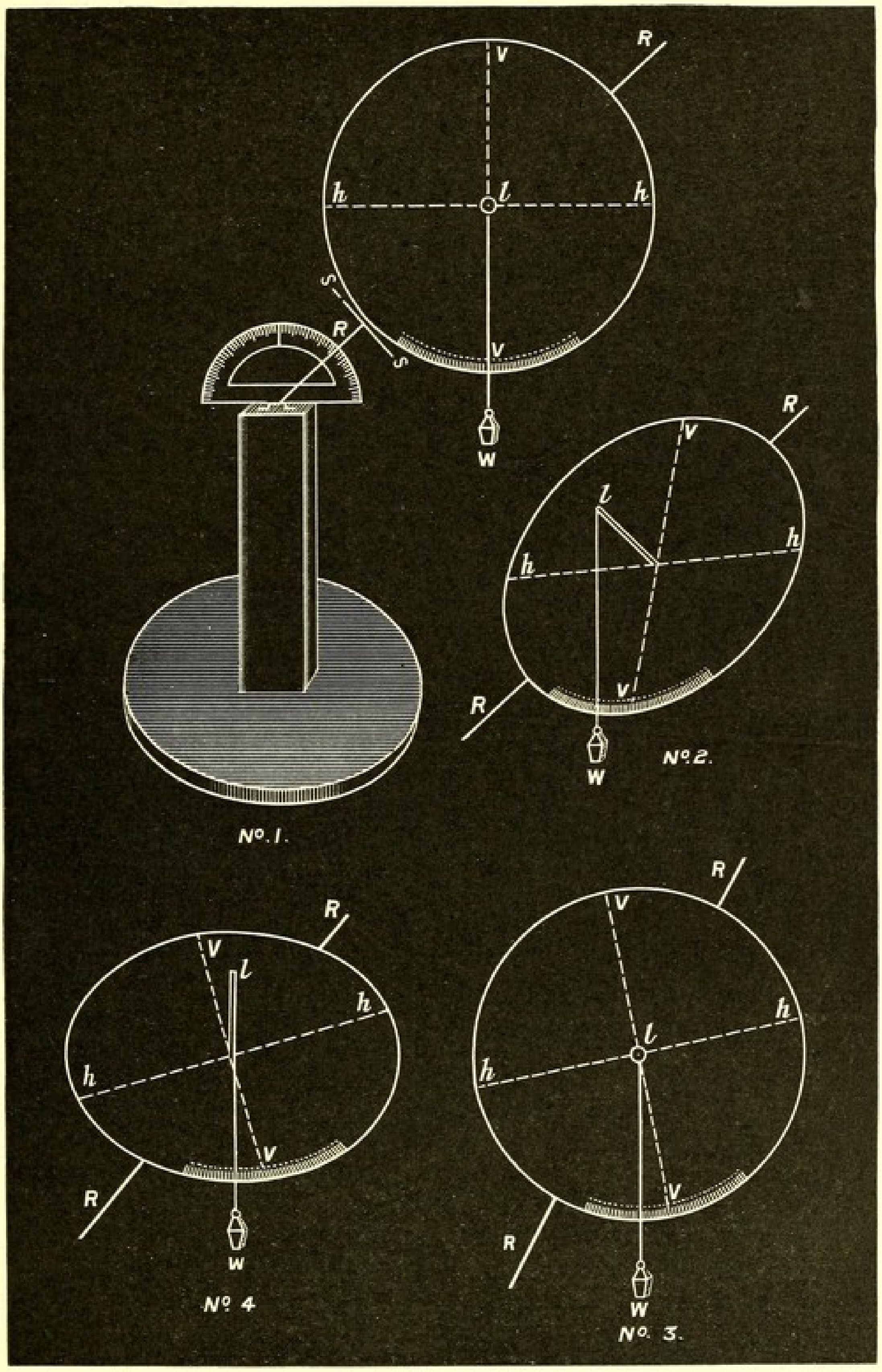


**Fig. 14**

The author's torsion calculator. No. 1.—The eye in its primary position. No. 2.—The eye looking up and to the right, showing equal and opposite inclinations of the horizontal and vertical meridians with reference to the fore-and-aft axis of the *head*. No. 3.—The eye looking as in No. 2, but showing equal similar inclinations of both meridians to the patient's right with reference to the fore-and-aft axis of the *eye*. No. 4.—Mode of reading same.

drawn upon it and fastened to a knitting needle *R R* which lies against some oblique diameter, about which it can rotate as axis.

The cardboard is transfixed through its center by another knitting needle *l* perpendicular to its plane and not, therefore, visible in No. 1 except as a round spot (being seen foreshortened) at *l*.

From the extremity of this needle (compare *l* in No. 2) is suspended a small weight *W* by a fine thread.

The cardboard is to represent the equatorial plane. The thread-bearing needle represents the "line of fixation," and is, therefore, perpendicular to the plane, under all circumstances.

**Mode of Use.**—First adjust the whole as in the primary position of the eye (No. 1, Fig. 14). The cardboard will be in a vertical transverse plane and the line of fixation will look straight forward.

Let the anterior extremity *l* of the thread-bearing needle represent the "point of fixation," and the thread itself be the ever-vertical line passing through the fixation point.

Now, let the observer hold his eye so as to be in a line with the thread-bearing needle; its extremity will then hide its length from view, and the appearance will be that presented in No. 1. The thread will appear to coincide with the vertical meridian *V V* of the cardboard, showing that there is no torsion.

To proceed to the next step: since any oblique motion of the eye from the primary position must take place about an axis in Listing's plane, let *R R* be that axis, and rotate the card, as in No. 2, just as the equatorial plane of the eye would be rotated actually. Let us, for instance, make the eye look upwards and to the (patient's) right, as in the figure. The thread-bearing knitting needle, which represents the line of fixation, now, therefore, points upwards and to the right. While it continues to do so, notice that, if your own eye is still in the same position as before, the appearance presented is that of No. 2.

From this point of view, the vertical meridian *V V* no longer appears parallel to the vertical thread, but slopes towards the patient's left, as if to indicate lævotorsion of the eye.

The horizontal meridian, on the other hand (*h h*), appears tilted from the horizontal in exactly the opposite direction, as if to indicate dextrotorsion of the eye.

Moreover, the apparent lævotorsion indicated by the tilt of the vertical meridian is exactly equal to the apparent dextrotorsion indicated by the tilt of the horizontal meridian.

From this point of view, therefore, namely, from directly in front of the patient's face, there is no torsion whatever. This proves what we have already said, that the eye is deprived of one degree of freedom, and that rotation about any axis in Listing's plane cannot have a component about a line perpendicular to that plane.

Are we to conclude that there is no false torsion, then? By no means; but we must look at the eye from the true point of view to see it, namely, along the length of its own visual axis, as already specified.

Let us do so. Leaving the model as in No. 2, let the observer move his own eye till he looks along the line of the knitting needle *l*, and now it is evident that both meridians tell the same story, for they are perpendicular to each other and both indicate that the eye is dextrotorted. This is illustrated in No. 3.

The amount of dextrotorsion can be read off from the graduated arc on the cardboard disk by seeing what degree appears crossed by the weighted thread. To facilitate doing this, the eye may be held lower down in the same vertical plane, taking care, as in No. 4, to keep the thread in apparent coincidence with the needle it hangs from.

A pretty way of demonstrating to others is to hold a strong light in such a position as to make the shadow of the thread pass through the center of the card, as in No. 4. This linear shadow will then record the amount of torsion on the scale. The light should be held on a slightly lower level than the center of the cardboard disk.

For greater accuracy, a rather better-made apparatus is desirable. In my own model the card is replaced by a graduated circle, of some white material, like ivory; and is pivoted at its center to the oblique axis, so that this can be brought to coincide with any required diameter, and the axis itself is, by a graduated half-circle, capable of adjustment to any required degree of obliquity. Moreover, the degree of rotation imparted to the cardboard disk is registered by a small graduated circle (*S S* in No. 1) fixed on the oblique axis perpendicular to it.

If accurately made, such a torsion calculator at once tells us the amount of secondary torsion which belongs to any motion of the eye from the primary position about no matter what axis or to what extent.

A very little experimenting with this apparatus will easily show the reader that if Listing's law be true the following facts are also true for binocular parallel movements of the eyes :

(*a*) Fixation upwards and to the right is accompanied by parallel dextrotorsion.

(*b*) Fixation downwards and to the right, by parallel lævotorsion.

(*c*) Fixation upwards and to the left, by parallel lævotorsion.

(*d*) Fixation downwards and to the left, by parallel dextrotorsion.

**Clinical Import.**—Though of great physiological interest, the clinical importance of secondary torsion and of Listing's law, which it expresses, is very small. It, or rather the unnatural absence of it, accounts for the obliquity of the false image in paralyses of the internal and external recti, during diagonal fixation ; and when a strong paralysis of one of these muscles is complicated by a feeble paresis of another muscle, the proper paretic torsion due to the slight paresis might conceivably be overborne by the false torsion in the opposite sense.

**Geometry of False Torsion.**—The torsion calculator makes it almost unnecessary to lead the reader into an analytical study of false torsion, and I will simply show how to obtain my formula.

To start with, we will assume Listing's law proved and suppose the eye to be in the primary position before the motion commences. Required : for any given rotation about any given diameter in Listing's plane, to find the amount of "false torsion."

It will serve our convenience best to select, not the vertical meridian of the retina, or the vertical meridian of the cornea, by which to gage the amount of torsion, but that diameter of Listing's plane in which it is intersected by the plane which passes through the vertical meridian of the cornea and the retina and which, therefore, is itself strictly vertical in the primary position of the eye. This diameter corresponds to the line *V V* on the cardboard model of Listing's plane in No. 1 of Fig. 14. We wish to ask, for any position of the eye : What is the angle included between this line and a vertical plane passing through the center of motion of the eyeball, and the point of fixation?

It is evident that if the eyeball were free to rotate unhinderedly about any oblique axis, this *vertical diameter of Listing's plane* (as we may call it) would describe two right cones with their vertices meeting at the center of motion of the eye, and they would be what are called "opposite" cones, since they have one axis in common, namely, the axis of rotation of the eye. Let Fig. 15 represent one of these cones, *C* being the center of motion of the eyeball, *O C* the axis of rotation and *V C* the vertical diameter of Listing's plane during the primary position of the eye, while *C n* is the same line after a given amount of rotation ; *V C* is, in fact, the generating line of the cone.

The triangle *V S C* lies in Listing's plane, and the angle formed between it and the plane *n O C* measures the rotation of the globe about the axis *O C*. Let us denote this angle of rotation (*n O V*), whose arc is *n V*, by the letter *R*; and let *I* denote the angle *O C V* by which the axis of rotation *O C* is inclined to the vertical.

It is this angle, indeed, by which we define the axis of rotation, for there are an infinite number of diameters in Listing's plane about which the eyeball might rotate, but only one for each specified angle from the vertical, though we need to take account of whether the inclination is positive (to the patient's right) or negative (to the patient's left).

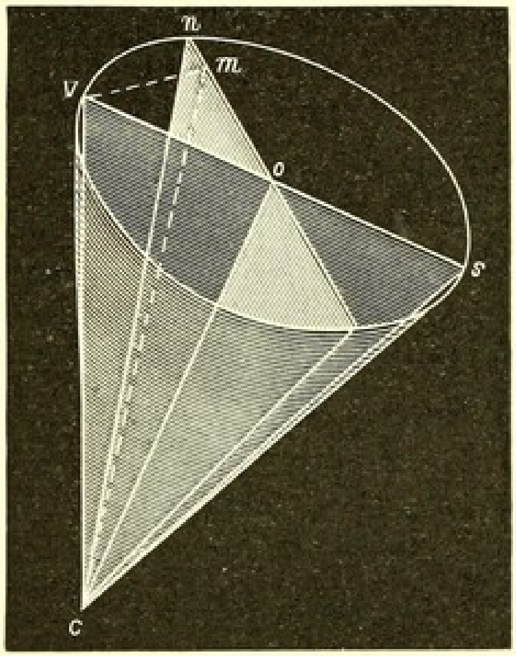


**Fig. 15**

Design proposed by author for solving false torsion. *C*.—Center of Motion of the eye. *V S C*.—Plane passing through *C*, perpendicular to the Visual axis. *n O C*.—Same Plane after Rotation of eye Up and to the Right about an oblique axis *O C*. *V m C*.—Vertical plane through *V C*, perpendicular to *n O C*. While *n C* was the Original Vertical Diameter of the eye in the Primary Position (since before rotation it coincided with *V C*), *m C* is the New Vertical Diameter—the angle between them (*n C m*) being the angle of Torsion.

From *V*, drop the perpendicular *V m* upon *O n*.

Then *m C n* gives us the angle of false torsion required; for *n C* is the position of the generating line at the close of the rotation, and shows the new position of the vertical diameter of Listing's plane, while the plane *m C V* is the vertical plane passing through the center of motion and the point of fixation, the angle between these two being the angle of torsion.

It is evident that the plane *m C V* is a vertical plane, since it passes through the vertical line *V C*.

It is equally easy to prove that the plane *m C V*, if prolonged, would pass through the fixation point, for it is perpendicular to the plane *n O C*, to which the line of fixation is also of necessity perpendicular, and they both pass through *C*; therefore, the line of fixation must lie in the plane, and conduct it, so to speak, to the fixation point.

Taking *V C* as unity—

Since $O\,V = \text{Sin. I}$

and $\dfrac{O\,m}{O\,V} = \text{Cos. R}$

$\therefore \quad O\,m = \text{Sin. I Cos. R.}$

Moreover, $O\,C = \text{Cos. I}$

$\therefore \quad \dfrac{O\,m}{O\,C} = \dfrac{\text{Sin. I Cos. R}}{\text{Cos. I}} = \text{Tan. I Cos. R.}$

But, $\dfrac{O\,m}{O\,C} = \text{Tan. (I} - \text{x)}$

$\therefore \quad \text{Tan. (I} - \text{x)} = \text{Tan. I Cos. R.}$

Or, $\text{x} = \text{I} - \text{Tan.}^{-1}\,\text{(Tan. I Cos. R).}$

Putting this into language :—The false torsion is equal to the angle from the vertical, or from the horizontal, of the axis about which the eye rotates, *less* the angle whose tangent is the multiple of the tangent of the inclination of the axis of motion with the cosine of the angle traversed by the line of fixation.

The following short table will give an idea of the amount of false torsion which takes place on looking in any diagonal direction midway between any two of the cardinal directions.

Since the greatest false torsion of which the eye is capable occurs at the extremities of these diagonals, we may see at once that it does not ever much exceed 10°.

ROTATION ABOUT AN AXIS 45° FROM THE HORIZONTAL.

| Degrees | 5° | 10° | 15° | 20° | 25° | 30° | 35° | 40° | 45° |
|---|---|---|---|---|---|---|---|---|---|
| Torsion | 6½′ | 26′ | 1° | 1°47′ | 2°49′ | 4°6′ | 5°40′ | 7°33′ | 9°44′ |

**Azimuth and Altitude.**—The ocular motions can, for exact work, be analyzed with reference to three principal axes, a vertical axis, a horizontal axis and an antero-posterior axis.

When the eye looks directly upwards or downwards it rotates round a horizontal (or transverse) axis.

When it looks directly to the right or left, it rotates round a vertical axis.

These will be recognized as the *cardinal* movements of the eye.

In astronomical language, we might call the upward and the downward motion, "motion in altitude," and the motion to right or left, "motion in azimuth," these being the terms that would be used were the eyes two telescopes.

Motion in *azimuth* may be illustrated by that of a weathercock : it is *motion about a vertical axis.*

Motion in *altitude* may be illustrated by a piece of cannon, or by a toilet looking glass : it is *motion about a horizontal axis.*

It will be seen that the cardinal motions of the eyes are those of either pure azimuth or pure altitude.

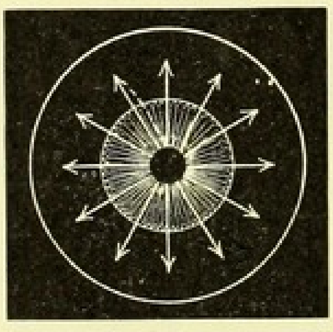

**Fig. 16**
To show how the eye reaches any new position by the shortest possible route.

When the visual axis, however, is directed obliquely to an object, altitude and azimuth are combined. What is so wonderful is that they are combined in the same proportion at every instant during the motion, so that the visual axis instead of first moving sideways, and then up and down, moves at once by the shortest route into its new position.

An astronomer would direct his telescope by first moving it in azimuth and then in altitude, but this is far too clumsy a plan for the eye, since it means two motions instead of one, and a longer route instead of the shortest. The visual axis, therefore, sweeps along whatever inclined plane is common to its initial position and its new position, and loses no time (Fig. 16). It is evident that in motion of this kind the globe must rotate about an axis perpendicular to this inclined plane, an axis, therefore, which is neither horizontal or vertical, but somewhere intermediate. All the same, it can be described in terms of its component azimuth and altitude *as if* it had reached its new position like a telescope. The horizontal component of the motion is the azimuth, and its vertical component the altitude.

When motion is to the right from the initial position, the azimuth is by astronomers called positive—when to the left, negative.

Similarly, motion upwards gives positive altitude, and motion downwards negative.

In analyzing any motion, it is a good plan to adhere to the rule of allowing azimuth the first place, or preference, over altitude, so that, for instance, a motion of $(-20^\circ + 10^\circ)$ means that there is negative azimuth of 20° with positive altitude of 10°, or, in other words, the eye looks 20° to the left and 10° upwards.

For ordinary clinical work, however, it is well to substitute for motion in azimuth, motion "to right and left" (*dextroduction* and *lævoduction*), which leaves it an open question whether it is about an axis strictly vertical, or with an inclination forwards or backwards. For motion in altitude, *elevation* and *depression* are suggested as terms which do not bind us too closely.

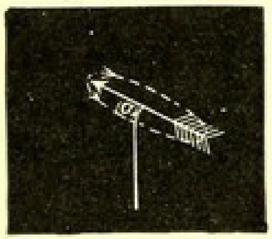

**Fig. 17**
Varying altitude (to illustrate torsionless motion according to Helmholtz).

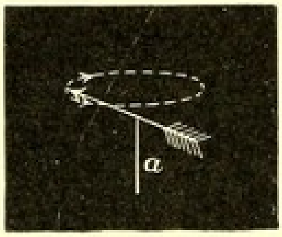


**Fig. 18**
Constant altitude (to illustrate torsionless motion according to Donders).

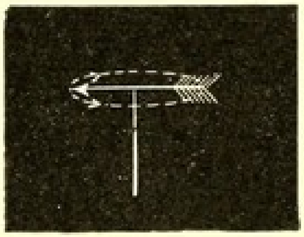

**Fig. 19**
No altitude

**Helmholtz's Plan** of analyzing the ocular motions was to consider the fixation plane (in which both the fixation lines lie) as first elevated or depressed, above (brow-wards) or below (chin-wards) its "initial position," by an angle called the "elevation angle" of fixation. Then, in this plane, the angle between its mesial line and the fixation line was called the side-turning angle. By this plan, however, the altitude of the fixation line steadily lessens as the lateral deviation increases, and it was partly its adoption which led to the apparent discrepancy between Helmholtz's laws of false torsion and those in the text-books. It may be illustrated in a simple way by a weathercock with a bent stem, as in Fig. 17, where motion in azimuth and in altitude are compounded. Fig. 19 illustrates pure motion in azimuth, and Fig. 18 motion in azimuth with a constant altitude, as in Donders' plan.

Since many of our tests are conducted with the patient facing a flat wall, it way be well to point out in what respects the two plans differ with reference to such a plane surface.

By Helmholtz's plan, horizontal lines on the wall represent lines of elevation of the visual plane, and if each is marked in tangents of degrees to right and left of a central zero, these represent the amount of lateral deflection. If, however, the lateral deflection take place first, during the primary position of the fixation plane, then elevation and depression of this plane makes the fixation line describe a hyperbolic curve on the wall, with its concavity outwards.

By the other plan, lines of equal altitude on the wall are hyperbolic curves with their concavity upward when the eves are elevated, and down-

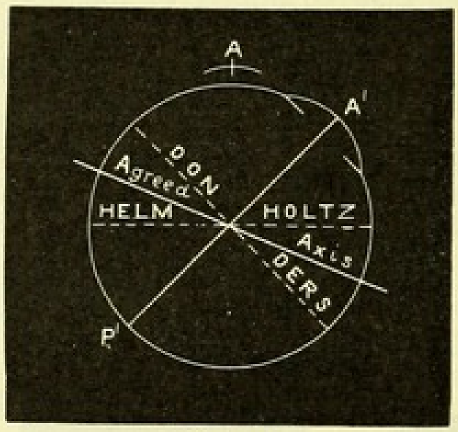


**Fig. 20**

Horizontal section of an eye abducted from $A$ to $A'$, to show the author's conception of the difference between the laws of false torsion formulated by Helmholtz and Donders.

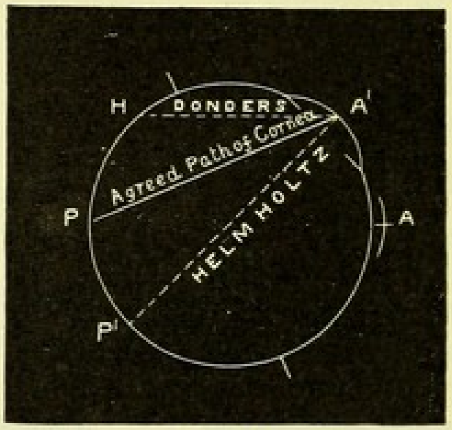


**Fig. 21**

Side view of an eye, seen in (orthographic) projection against a vertical plane, superducted from $A$ to $A'$, the three circles being projected as straight lines, to illustrate author's conception of what would be the path of no torsion according to Donders, and what would be the path of no torsion according to Helmholtz, while the actual torsion is as if the cornea pursued the intermediate path towards $P$.

ward when depressed; but when the eyes are first deflected to the right or left, elevation or depression makes the fixation line describe vertical lines on the wall.

In Figs. 20 and 21 I have represented graphically the different points of view taken by Helmholtz and Donders. Fig. 20 is a horizontal section of an eye, viewed from above, and abducted from $A$ to $A'$. The diameter which I have named "agreed axis" is the one about which rotation would produce exactly the false torsion which all observers are agreed upon.

Of the two authorities in question, each adopts the diameter indicated by his name as the axis about which torsionless rotation would take place. Since these diameters are inclined at equal angles to the "agreed axes," though on opposite sides, Helmholtz's tables hold good for Donders' plan if only the signs be changed.

Fig. 21 shows a side view of an eyeball, not in section but solid, though viewed as projected on to a vertical plane; to demonstrate that for any given elevation of the cornea from $A$ to $A'$, the path of zero torsion adopted by such authority is that circle indicated by his name, the path which would give the actually observed torsion bisecting the angle between them. In fact, we may say that, for any secondary position of the eye whatever, the false torsion is the same *as if* the cornea had reached that position by vertical motion, and then through an arc of a circle passing through the center of the cornea ($A'$) and the primary position in space ($P$) of the posterior pole of the eye. It will not, of course, be supposed that the cornea actually takes this path, but its torsion is the same as if it had taken it.

## CHAPTER III

### Individual Ocular Muscles

**The Laws of Motion are not Explained by the Anatomy of the Muscles.**—Our studies of the ocular *motions* up to this point have been quite independent of the ocular muscles, and our deductions from them would not have suffered had we possessed no knowledge of their anatomy.

No sooner do we investigate the musculature, than we find the remark of Helmholtz to be true, that "The manner in which the eye is fixed presents no obstacles to any rotations whatever of a moderate amplitude: the existing muscles would suffice equally well to rotate the eye about any given axis whatever."

But, he adds, "In the ordinary circumstances of normal vision the eye is far from executing all the movements of which the mechanical possibility is recognized."* These remarks are confirmed to a considerable extent by the phenomena of paralysis of isolated ocular muscles.

**The Laws Explained by Innervation.**—The limitation, therefore, of the parallel ocular motions to rotations about diameters perpendicular to the visual axis, is a limitation which finds no proper explanation from anatomy, but is due almost entirely to cerebral co-ordination.

If we except the internal and external recti, any one of the other muscles, acting in an isolated way, would rotate the eye about an axis lying far out of the perpendicular; but, as a matter of fact, they never do act in an isolated way, but in innervational conjunction with some other muscle in such a manner that the resultant axis is perpendicular.

**Brief Description of the Recti.**—Each eyeball is controlled by four recti and two obliques. The recti spring from an oval tendinous tube at the apex of the orbit. Since, however, there is not quite sufficient room for their origins round the optic foramen, this tube spans the sphenoidal fissure to be attached to the well-known spine on its lower margin. From the *orbital* surface of this common tendon, so as least to affect the optic nerve by their contraction,

*"Optique Physiologique," p. 598.

spring the muscular fibres of the four muscles, those of the superior rectus being almost continuous with those of the levator palpebrae at first, though separating later, while the internal rectus is contiguous to the origin of the superior oblique. From the upper span across the sphenoidal fissure, as well as from the spine itself, springs the external rectus, while the lower span gives rise to the inferior rectus.

The *internal rectus* proceeds almost straight forwards and lies rather close to the slightly-convex inner wall of the orbit.

The *external rectus* proceeds forwards and outwards to the outer side of the globe.

The *superior* and *inferior recti* proceed forwards and somewhat outwards to the upper and lower parts of the globe respectively.

**Spiral of Insertions.**—The insertions of the internal, inferior, external and superior recti lie, in round numbers, five, six, seven and eight millimeters respectively from the corneal margin (Tillaux). The internal rectus, therefore, has the greatest mechanical advantage and the inferior next.

**Description of Insertions.**—The insertions of the internal and external recti form two perpendicular lines, so that their tendons appear to have rectangular extremities. The tendon of the internal rectus is strong and well defined: that of the external is thinner, its margins passing almost insensibly into the lateral expansions connected with Tenon's capsule.

The superior and inferior recti have oblique insertions, the outer extremities of which are rounded and lie farther back than the inner extremities. In operations on their tendons this should be remembered, so as to approach them on their inner, more accessible, side. Otherwise some difficulty may be experienced in hooking them up.

**Relative Strength.**—Of all the muscles, the internal rectus is the strongest, or at least the most bulky, weighing, according to Volkmann, .747 of a gramme; the external rectus comes next, weighing .715 of a gramme; the inferior rectus weighs .671, and the superior rectus (the weakest of all) .514 of a gramme.

**Description of Obliques.**—The *superior oblique* arises from the medial side of the upper part of the origin of the internal rectus and runs forward; but its tendon is reflected in a fibro-cartilaginous pulley or "trochlea" near the upper inner corner of the orbital outlet, whence it passes backwards and outwards over the orbital surface of the superior rectus tendon to be attached to the globe by a flattened expansion mostly in the upper and outer quadrant of its posterior hemisphere. The line of insertion is subject to considerable variation, its direction, according to Fuchs, being more longitudinal in myopes. In emmetropes it forms nearly equal angles with the antero-posterior and transverse meridians of the globe. Though the anatomical origin of the superior oblique lies on the apex of the orbit, the pulley may be regarded as its virtual origin.

The *inferior oblique* arises from a little depression in the bone near the lower and inner corner of the orbital outlet, and passes backwards and outwards, beneath the orbital surface of the inferior rectus, continuing to curve round the globe between it and the external rectus, till, without a tendon, its muscular fibers gain insertion about a quarter of an inch from the tendon of the superior oblique, either in the same quadrant or between the upper outer and the lower outer quadrants of the posterior hemisphere. The line of insertion is not parallel to that of the superior oblique.

**Why a Pulley at all?**—Many must have wondered why *one* of the oblique muscles should have a pulley and the other not. There must, of course, be a reason, and the following consideration is advanced as a possible one :

The speed with which a muscle's point of insertion moves is proportional to its length. By this it is not meant that a long muscle takes necessarily a different time to attain its maximum contraction, from a short one ; but that in the same period of time it will move its insertion through more space than a short one and, therefore, with a greater speed of motion. The obliques, therefore, must have a certain length if they are to keep pace with the recti ;* and this length could not be afforded were they both to have origins similar to that of the inferior oblique, unless, indeed, they passed each other in curling round the globe, which would spoil their action, for it is advantageous that their insertions should be opposite each other, rather than side by side.

To secure sufficient length for its muscular belly, the inferior oblique has to curl round more than its own share of the globe, and this would leave the superior oblique short. In fact, to gain more space, the inferior oblique dispenses with a tendon of insertion altogether, its muscular fibers extending quite to its attachment.

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* Really, the insertions of the obliques move more slowly than those of the recti during most movements of the eyes.

**Why the Superior Oblique and not the Inferior?**—Why, then, it may be asked, does the inferior oblique not have the pulley instead of the superior, seeing it is the inferior which is supplied by the third nerve and thus might be expected to rise in company with the third-nerve recti, rather than the superior oblique, which is supplied by the fourth nerve?

The reason may just possibly be this: that prolonged looking downwards is more important for daily work than looking upwards, a view which is confirmed by the fact that the continuous downward excursions of the eye are more amply provided for than the upward excursions.

The center of motion of the eyeball approximates more closely to the geometrical center of the eye on looking downwards than on looking in any other direction, showing that the mechanical resistance is least during this motion and, moreover, the eye can make a more extended excursion downwards than upwards. The superior oblique, therefore, which is a subductor of the globe, might be expected to have the most advantageous arrangement accorded to it. A free muscular belly, even though complicated with a pulley, is perhaps if not stronger, at least more delicately efficient than a muscular belly which traverses tissues in contact with the globe and is embraced by a check-ligament (Fig. 11). If, on the other hand, both muscles had pulleys, the pulley-complication would be doubled unnecessarily.*

**Everything for Speed.**—In some other parts of the body the muscles are constructed for strength rather than speed, but with the eyeball everything is adapted for speed.

The greater the number of muscular fibres ranged *side by side* the *stronger* is a muscle, and the greater the number arranged *end to end* the *quicker* it is. The bi-penniform arrangement, *e. g.*, of the rectus femoris, is a beautiful example of adaptation for strength at the expense of speed, the muscular length being considerably less, and the muscular breadth being considerably more, than the actual length and breadth of the muscle as a whole. The muscular length is found by measuring along the lines of fibres from one tendon to the other. There is no such marked arrangement as this in the muscles of the orbit, where speed is more desirable

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* Mauthner has shown that in paralysis of the inferior oblique the vertical separation of the double images is greater than in paralysis of the superior oblique. But then the superior rectus is very much weaker than the inferior rectus, and Mauthner's observation may only show that the difference between the obliques is less than that between the recti.

than strength and where, therefore, a certain length of belly is indispensable.

**Touching Point.**—The point at which a muscle, as we trace it forwards, first touches the globe, or its momentary insertion, is continually changing its location with every movement of the eye. The "arc of contact," therefore, along which the muscle remains applied to the globe, and which extends from the touching point to the anatomical insertion, is correspondingly ever varying in length. Its variations, I believe, however, are tempered by the disposition of Tenon's fascia, so that in the extreme rotations of the eye, the arc of contact is not abolished so quickly as calculations based on the muscles only would lead us to expect.

Thus, in the case of the internal rectus, it is easy to calculate that the arc of contact, while the eye looks straight forwards, is about 36° (from the center of motion), yet many eyes can be adducted 50° or perhaps even 60° at a push, and it is not likely that the arc of contact ceases at 36° or the eye would be tugged at and distorted. The "collarettes" or "intra-capsular ligaments," as they are called, must tend to bind the tendon longer to the globe so as not to let them so soon part company.

**Terminology.**—When the cornea is drawn toward the temple the eye is said to be *abducted;* when towards the nose, *adducted;* when raised, we may call it *elevated*; when lowered, *depressed.*

When the eye is twisted about its own axis so as to make the cornea revolve like a wheel, we may call it *torted; intorted* when the upper segment of the cornea revolves towards the nose, and *extorted* when it revolves towards the temple. I have found it convenient also to speak of *dextroduction*, *laevoduction*, *dextrotorsion* and *laevotorsion.*

**Prime Muscular Functions.**—Each eye possesses one muscle pre-eminent for abduction—the external rectus; another for adduction—the internal rectus; for elevation—the superior rectus; for depression—the inferior rectus; for intorsion—the superior oblique; for extorsion—the inferior oblique.

**Subsidiary Functions.**—But besides these "prime" actions, each muscle has "secondary"* actions. This is least so with the internal and external recti, which are pure adductors and abductors respectively, except when the eyes are elevated or depressed.

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* At Prof. Savage's suggestion, I have altered the word "subsidiary" to "secondary," as more euphonious.

They have subsidiary vertical and torsional effects, but I believe to a far less extent than has been supposed, owing to the restraints imposed by the collarettes and Tenon's fascia, which make the tendons share to some extent any change of direction imparted to the eye.*

**Medial Origins of Muscles.**—With regard to the secondary effects of the superior and inferior recti and the obliques, we may assist the memory by recollecting that *all* the ocular muscles, without exception, spring from origins *nearer the median plane* than their insertions.

Hence, the superior and inferior recti, being inserted into the anterior hemisphere of the globe, pull it nearer the median plane, *i. e.*, *ad*duct the cornea ; whereas, the obliques, being inserted into the posterior hemisphere of the globe, pull their insertions towards the median plane, *i. e.*, *ab*duct the cornea.

Moreover, in consequence of the same medial disposition of the muscular origins, those muscles which proceed to the upper hemisphere of the globe by pulling their insertions inwards *in*tort the cornea ; and those which proceed to the lower hemisphere of the globe, since they also draw their insertions inwards, *ex*tort the cornea.

We may say then that the *superior* muscles cause intorsion, and the *inferior* muscles extorsion ; the *obliques* abduction, and the *recti* (superior and inferior) adduction.

Thus the *superior rectus*, besides elevating the cornea, intorts the eye, because its insertion is "superior," and adducts it because it is inserted into the anterior hemisphere.

The *inferior rectus*, besides depressing the cornea, causes extorsion (being "inferior") and adduction (being inserted into the anterior hemisphere of the globe).

The *superior oblique* causes, besides its proper intorsion (from being "superior"), depression of the cornea from the upper character of its insertion, and abduction (being inserted into the posterior hemisphere of the globe).

The *inferior oblique* causes, besides its proper extorsion (from being "inferior"), elevation of the cornea because its insertion is inferior and its origin anterior, and causes abduction from the posterior character of its insertion.

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*Though the reader need concern himself but little with these unimportant considerations, on looking up, the *external rectus* must be a slight superductor and intortor, and on looking down a slight subductor and extortor. On looking up, the *internal rectus* must be a slight superductor and extortor ; and on looking down, a slight subductor and intortor.

**Inverse Proportions of Prime and "Secondary" Actions.**—We now come to a point of considerable clinical importance.

All the secondary effects of the various muscles which we have just recounted are at the expense of their prime actions. The energy expended in producing them represents so much loss in the prime action of the muscle.

In those positions of the globe, therefore, where we find secondary effects of a muscle at their minimum, the prime effect is at its maximum, and *vice versa.*

**Lateral Superductors and Subductors.**—The superior rectus is a "lateral" sursumductor, and the inferior rectus a "lateral" dursumductor, because their elevating and depressing effect is greatest when the eye is sufficiently abducted towards the temple for their vertical power to be uncomplicated and their secondary effects to become practically nil.

The more the eye is, on the other hand, adducted, the greater become their secondary adducting and torsional effects, and the less efficient they are for the vertical movements of the eye.

When we come to the diagnosis of ocular paralysis we shall find the advantage of knowing that the maximum torsional effect of a muscle occurs when the eye looks to the opposite side from that in which its maximum vertical effect occurs.

**Medial Superductors and Subductors.**—The *obliques* have their greatest torsional effect when the eye looks outwards, because then they form the greatest angle with the optic axis, and since their greatest effect on the vertical motions of the eye is found on looking towards the nose, the superior oblique is a "medial" depressor, and the inferior oblique a "medial" elevator.

While the reasons for these facts are no doubt self-evident, their fuller consideration requires a study of the "muscular planes" and "muscular axes."

**Lines of Force.**—Owing to the existence of an "arc of contact," the muscular forces acting on the globe must be tangential forces. There is, therefore, one tangent line to the globe for each muscle which indicates its direction of force.

In the primary position of the eye the lines of force probably extend from the "touching points" of the several muscles to their orbital origins, or the trochlea in the case of the superior oblique.

When the eye is moved away from the primary position, the lines of force are, I believe, more or less diverted by Tenon's fascia acting as a pulley, or at least exerting an elastic side-traction where the "collarettes" exist.

**Muscular Planes.**—When we have a force acting tangentially on a rotating body, confined as by a center of motion, and the line of that force is given, the plane of force is evident at once. It is the plane which passes through the line of force and the center of

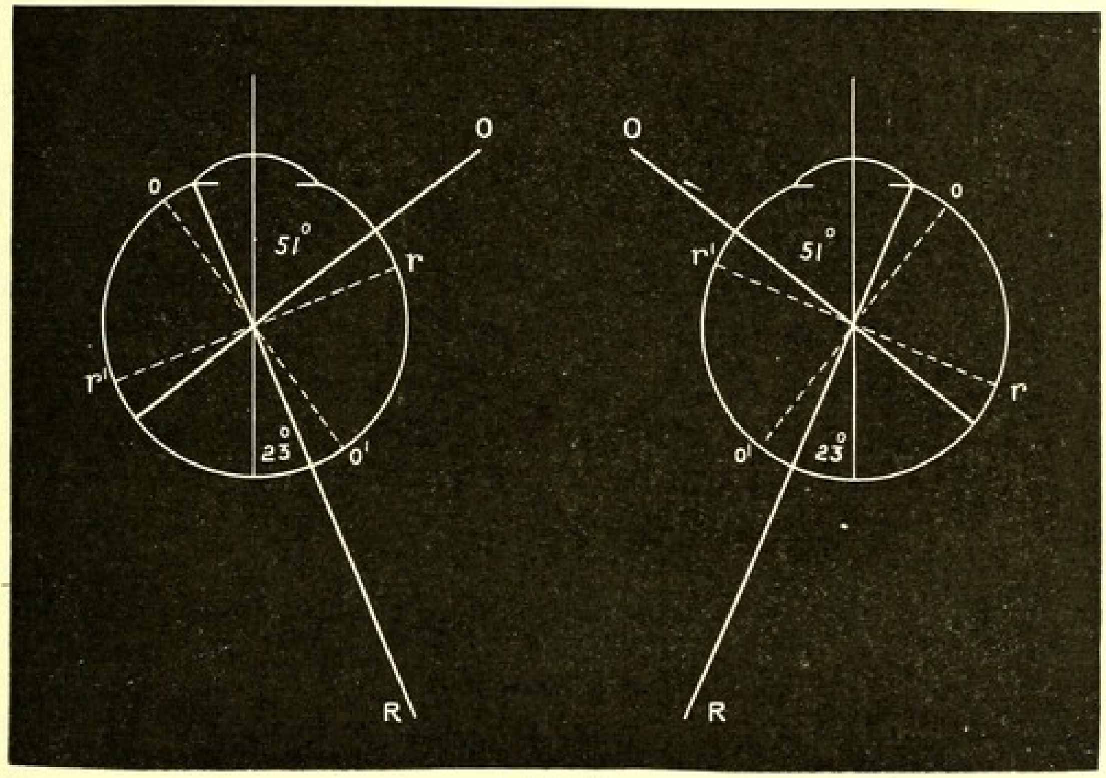


**Fig. 22**

The Muscular Planes and Axes. *O*—The muscular planes, and *o o'* the axes of the obliques. *R*—The muscular planes, and *r r'* the axes of the recti.

motion, and in the case of the eye, is called a "muscular plane," there being one muscular plane for each muscle.

The muscular planes, therefore, all agree in passing through the center of motion, but differ in that each extends thence through the line of force of its own muscle.

**Three Pairs.**—The muscular planes of the *internal* and *external recti* are practically horizontal and identical.

Those of the *superior* and *inferior recti* are generally also supposed to be identical, but vertical, forming an angle with the median plane, which is estimated by Landolt at 27° in accordance with the well-known anatomical fact that these recti, instead of running directly forwards, run forwards and somewhat outwards to their insertion.

In a horizontal section of the eye, as shown in Fig. 22, their common muscular planes are represented *in section* by the lines *R*.

The muscular planes of the *obliques* are similarly supposed to be identical and, therefore, vertical, but running, of course, backwards and inwards instead of forwards and outwards, so as to form an angle with the median plane estimated by Landolt at 51°.

In Fig. 22 the common muscular planes of the obliques are represented in section by the lines *O*.

**Properties of Muscular Planes.**—Each muscular plane possesses this property, that if a single muscle were to contract, the mid point of its insertion into the sclerotic would not move out of the plane, and though all the points contained in the plane would move, the plane itself remains fixed in space.

Every muscular plane, since it passes through the center of motion, must approximately bisect the eye and cut its surface in a great circle. All points on the surface of the eyeball not lying in this circle, will, when the muscle contracts, also move in smaller parallel circles, and the greater the distance of each surface point from the muscular plane, the smaller the circle in which it moves.

When the center of the cornea, therefore, lies actually in the muscular plane of a muscle, as it does, for example, in that of the superior rectus, when the eye is abducted 27°, the motion of the cornea under the influence of that muscle is greatest, and it becomes less and less the more the cornea is moved away from the muscular plane by adduction of the eye.

We have seen that the parallel circles of motion on the surface of the globe become smaller and smaller as they lie farther and farther from the muscular plane.

This goes on till at last they are reduced to a point on each side which remains fixed in space while the globe rotates.

These points, being those on the globe's surface which are farthest removed from the muscular plane, are the poles of the "muscular circle," and the diameter of the globe which unites them and which, therefore, remains fixed in space with them, is the "axis of rotation" and is strictly perpendicular to the muscular plane.

**Axis of Rotation.**—To find the axis of rotation for any muscle, we must first find the muscular plane; then a line perpendicular to it, and passing through the center of motion is the axis of rotation. In other words, the muscular plane cuts the surface of the globe in a circle, the axis of which is the axis of rotation.*

Fig. 22 shows the axes of rotation as usually figured.

* Though it is usual in opathalmology to speak of the axis of rotation as a diameter, yet it is defined physically by the *radius* perpendicular to the muscular plane, on that side of it which represents the sense in which the contraction of the muscle makes the eyeball rotate.

Since the superior and inferior recti are supposed to have one muscular plane in common, they have a common axis of rotation ($r\ r'$) about which, however, they rotate the eye in opposite senses.

The obliques are also supposed to have a common horizontal axis, shown by $o\ o'$ in the same figure.

**Are the Axes, Supposed to be Identical, Really So?**—Let us now ask: Do the superior and inferior recti really rotate the globe about one axis in common? I am not sure that they do, for were it so, isolated paralysis of either muscle would (*cæteris paribus*), during the primary attitude of the sound eye, adduct the other, so as to cause homonymous diplopia, and this is contrary to most recorded clinical experience.*

Similarly, it is doubtful if the two obliques rotate the globe about an axis common to them both, for if this were true, paralysis of either would tend to cause crossed diplopia during the primary attitude of the sound eye, which is also contrary to usual clinical experience.

It is true that sometimes crossed diplopia does occur in paralysis of the obliques, but this has hitherto been explained, on Mauthner's hypothesis, by the liberation of previously-existing latent divergence (exophoria) of the two eyes.

The reader may feel inclined to object: "Surely, if contraction of a muscle causes adduction (as we know to be the case with the superior and inferior rectus), its paralysis will result in abduction!"

This is true when the sound eye is raised or lowered towards the area of maximum diplopia, for the superior rectus is an adductor when it superducts the eye, and the inferior rectus when it subducts the eye; but what we are now considering is what they do during the primary position of the sound eye.

**Double Contraction.**—If it were possible for both the superior and the inferior rectus to contract simultaneously, the effect on the rotation of the eye in its primary position would be nil if they really have but one axis in common. They would simply tend to draw the eye as a whole backwards and slightly inwards towards the apex of the orbit, just as if an elastic string were tied by one end to the optic foramen, and by the other end (if possible) to the center of motion of the eye. The eye, therefore, would be neither adducted nor abducted.

**Single Contraction.**—If, however, either muscle contracted alone, the vertical motion of the cornea would be accompanied by a proportionately increasing *ad*duction.

**Single Paralysis.**—So far the reader will readily agree; but the next proposition is quite as simple: that if either muscle were paralyzed, the paralytic displacement of the cornea should (during the primary position of the sound eye) be accompanied with a precisely corresponding proportion of *ad*duction also. For *if the axis be common* to both, paralysis of, say, the superior rectus, must cause the same effects as contraction of the inferior.

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*Since this proposition requires a good deal of thinking out before becoming evident to every reader, the smaller print may, with advantage, be skipped on first reading.

When the eyeball is in equilibrium, each tension is balanced by the resultant of all the other tensions, and if the increase of any one tension rotates the eyeball about a given axis the resultant of all the other tensions would, in the absence of that one, rotate the eyeball about the very same axis, only in the opposite sense. But this is just, in kind, if not in degree, what the other rectus does when it contracts, for it also rotates the eyeball about this same axis in the opposite sense.*

**Arc of Contact.**—This name has already been spoken of as given to the line along which a muscle and its tendon embrace the surface of the globe.

The actual insertions of the tendons are in advance of the points where the muscles first reach the surface of the globe tangentially.

The touching points are those we must take account of in studying the dynamics of the ocular muscles, but we really know much less about them than is usually taken for granted, since they are modified by Tenon's capsule in a way which it is impossible to determine precisely.

This shows it to be all the more judicious not to study the ocular muscles synthetically, *i. e.*, by argument from their anatomy, but analytically, by close observation of the actual results of their physiological action and pathological failures. Donders placed great emphasis on this principle.

**Ophthalmotropes.**—For teaching purposes the synthetical study is, however, needful and, provided we confine ourselves only to broad principles, we shall not go far astray.

A number of *ophthalmotropes* have been invented from time to time, and of these I prefer Landolt's and Anderson Stuart's as the best. Their purpose is to represent, in the form of a model, the characteristic functions of the several muscles in isolated action, as in Figs. 23 and 24.

**Landolt's Ball.**—Another ingenious device by Landolt is his "india-rubber ball" (Fig. 25), which any reader can easily mark for himself.

His own description is as follows: "Take a simple india-rubber ball, depict upon it the cornea, the vertical meridian and the horizontal meridian. On the latter, mark, at 39° from the anterior

*This amounts to saying that, during the primary position of the sound eye, the paralysis of the superior rectus produces the same effect as slight spasm of the inferior, if the usual single-axis hypothesis be true. Clearly, therefore, either it is not true, or else previous clinical observations in the primary area of the motor field have been misleading. I will not attempt to say which is the case.

pole (center of the cornea), the anterior extremity of the axis of the obliques (*O*), and at 63° on the opposite side (*R*), the axis of the superior and inferior recti."

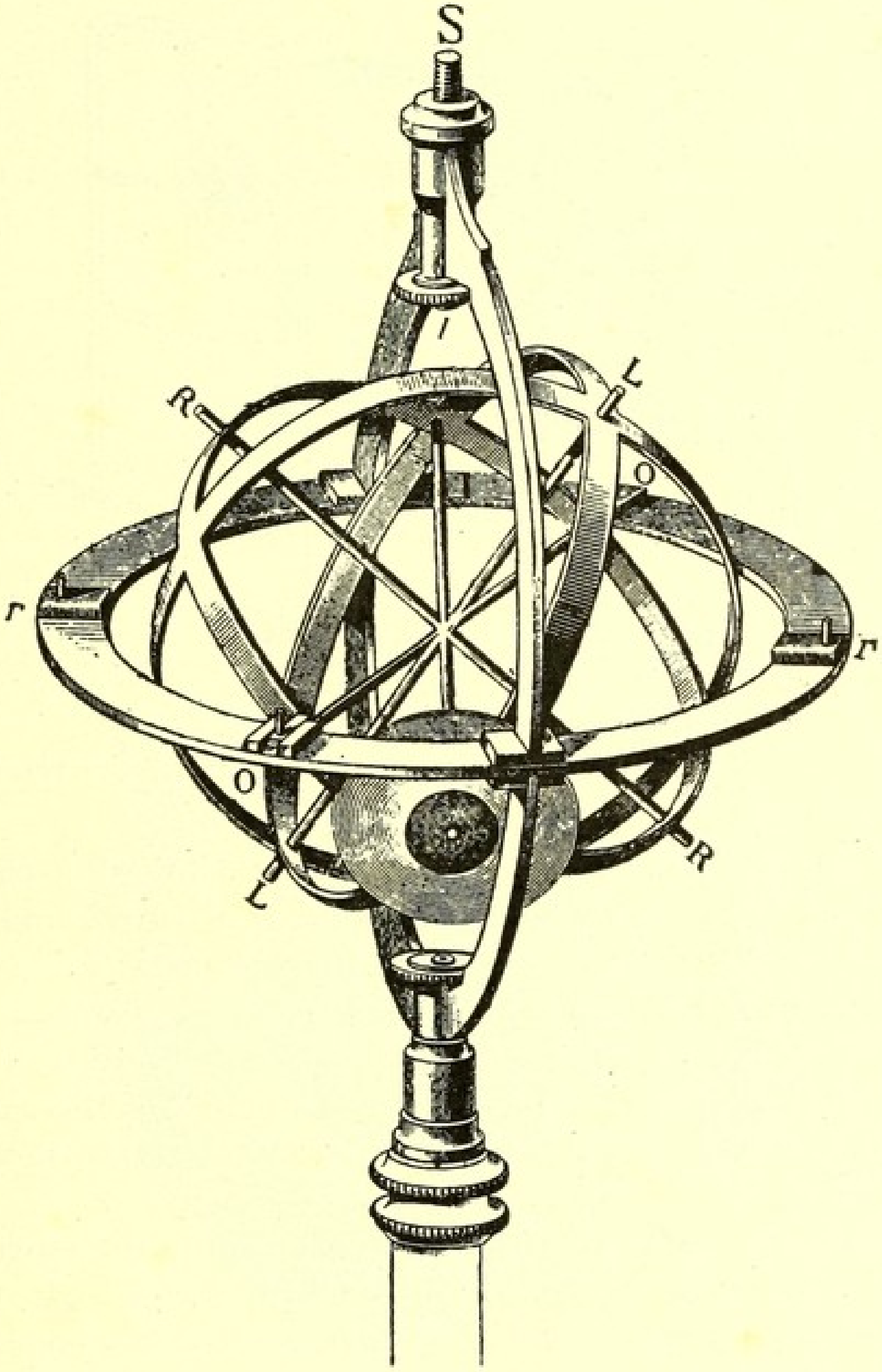



**Fig. 23**

Landolt's Ophthalmotrope. The eye is seen under the action of the superior oblique, *O O* being the axis of the oblique.

Now suppose, for example, we wish to demonstrate the action of the superior oblique, we reason thus : this muscle makes all the points of the cornea describe parts of parallel circles about its axis.

Taking a pair of compasses, therefore, we open them so that one of the points shall correspond with the anterior extremity of the axis of the oblique muscle, the other to the center of the cornea.

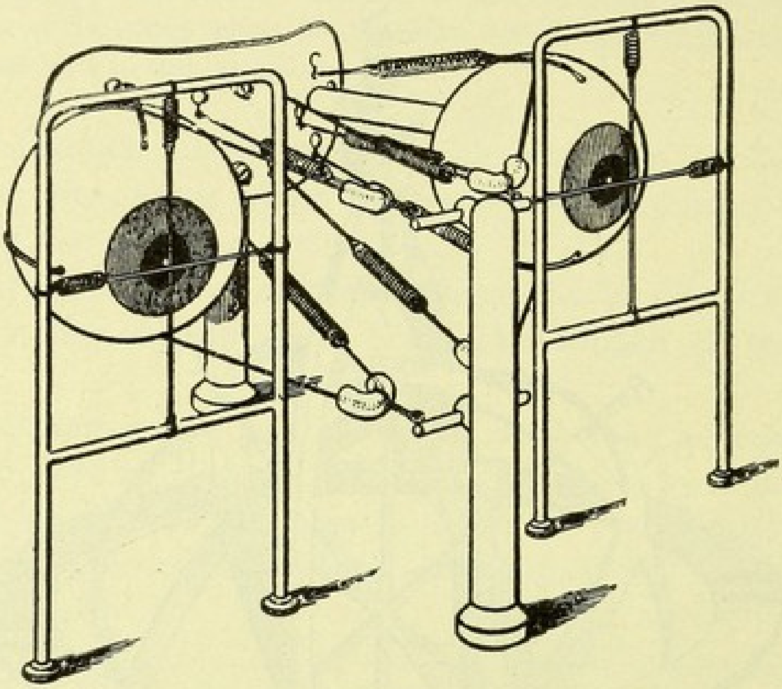


**Fig. 24**

Anderson Stuart's Model of the Ocular Muscles (the inferior obliques should not have a pulley)

Keeping the first point fixed, we trace with the other the circle, of which a part is traversed by the apex of the cornea under the influence of the contraction of the superior oblique.

"If we wish to know where this apex of the cornea is found after a rotation, for example, of 40°, we have only to trace a straight line, starting from the anterior extremity of the axis and forming an angle of 40° with the horizontal (*below* it for the *superior* oblique, *above* it for the inferior oblique).

"The point, $O'$ or $R'$, where this line meets the circle indicates the position of the corneal apex which corresponds to the required rotation. We see thus, at once, in what direction and to what extent it deviates from the horizontal as well as from the vertical.

"As for the slope which the vertical meridian of the cornea will have acquired at the same time, it is of necessity perpendicular to the line which we have just traced and passes through the point which it has discovered for us to be the center of the cornea. That is evident. This very line is, in short, no other than a part of the horizontal meridian, sloped by the muscular contraction; it is perpendicular to the vertical meridian.

"It is thus that in our figure the two black stripes indicate the inclination impressed upon the vertical meridian of the right eye by the superior oblique *O'* and by the inferior rectus *R'*.

"By dropping a perpendicular from the points *O'* and *R'* upon the horizontal meridian, we get the amount of *depression* (*O' h* and *R' h*) produced by the muscles in question.

"The perpendicular dropped from these two points *O'* and *R'* upon the vertical meridian correspond to the amount of *abduction* (*O' V*) caused by the oblique, and to the amount of *adduction* caused by the rectus."

**With Landolt's Ball the Sound Eye is Supposed in its Primary Position.**—It should be remarked that Landolt's ball as thus made only represents the truth when the internal and external recti are

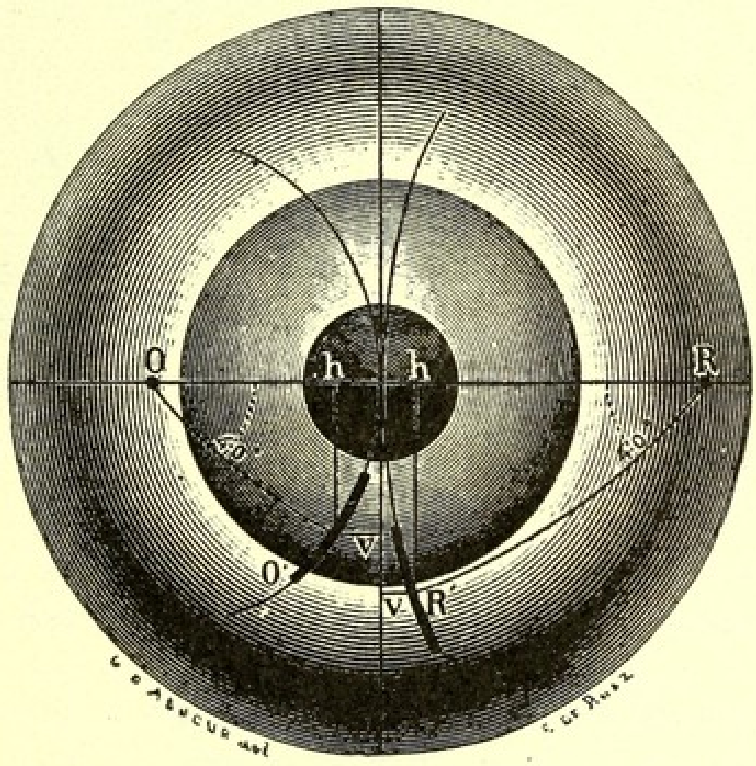



**Fig. 25**
Landolt's Ball

quiescent, for the more the eye is adducted by the internal rectus, the farther is the anterior extremity of the oblique axis removed from the cornea, making the arc for the oblique become that of a larger circle and the arc for the rectus that of a smaller circle.

Conversely, the more the eye is abducted by the external rectus, the smaller becomes the circle for the oblique, till perhaps it becomes nil, showing that then the oblique is purely torsional in its action : and the larger becomes the circle for the rectus, till at last it becomes a straight line, showing that then the rectus is a superductor or subductor.

Furthermore, since the circles on Landolt's ball map out the *paths* followed by the apex of the cornea under the action of individual muscles, and since it is based on the approximation that the obliques have one and the superior and the inferior recti also have one horizontal axis in common, we may well use it to illustrate that

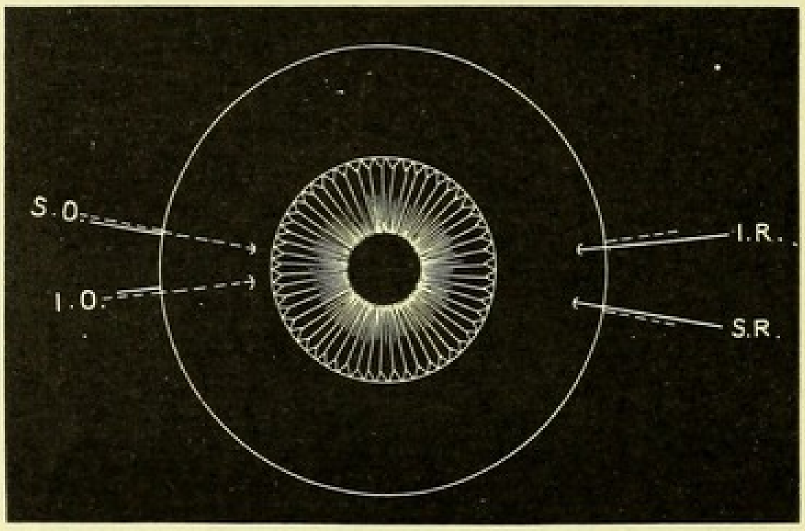



**Fig 26**

To show, if the axes are tilted, the nature of the tilting, *I. R.* and *S. R.* being the axes of the Superior and Inferior Recti, and *S. O.* and *I. O.* those of the Superior and Inferior Obliques.

if this be true, paralysis of any one of these muscles would bring about the opposite horizontal condition from that which is generally believed.

For if contraction, say, of the superior rectus, move the apex of the cornea in a circle as marked on the ball, its paralysis will move it in the same circle but in the opposite direction, *i. e.*, just as slight contraction of the inferior rectus would move it, causing, therefore, adduction in each case.

**Tilted Axes.**—If clinical observation shows abduction to be the undoubted result of *uncomplicated* paralysis of the superior or inferior rectus during the primary position of the sound eye, then the axes of rotation for these muscles must be regarded as inclined to the horizontal in opposite directions ; the axis for the superior rectus having its inner end lower, and that for the inferior rectus having its inner end higher, than the horizontal meridian.

Similarly, if uncomplicated paralysis of either oblique cause adduction, under similar conditions, the axis of rotation for the superior oblique must have its outer end higher, and that for the inferior oblique lower, than the horizontal meridian.

I have represented this in Fig. 26, which shows an india-rubber ball traversed by knitting-needles to represent the axes.

As a matter of fact, it is extremely difficult to ensure that any paralysis is uncomplicated by previously-existing latent squint, so that clinical records are very little to be trusted on this point, unless they are made with special reference to it.

The theory of tilted axes is, I find, far from new, Meissner having taught them, and later Continental writers having owned them theoretically as true, though deeming the convenient approximation of horizontal axes sufficiently accurate for practical purposes, and for clinical deduction perhaps.

## CHAPTER IV

### Associated Muscles in a Single Eye

**Isolated Contraction of Some Muscles Unknown.**--Our study of the ocular motions in Chapter II will have shown us that isolated action is forbidden to at least four of the muscles of each eye, since neither the superior or inferior recti, nor the obliques, can act alone without violating Listing's law, by which, it will be remembered, all rotations from the primary position are forbidden to the healthy eye except those about axes in a vertical plane passing through the center of motion of the eye, perpendicular to the visual line in its primary position. But neither the axis for the obliques nor that for the superior and inferior recti lie in this plane; therefore, no one of these muscles can contract without some associated muscle acting with it in that perfect proportion required to keep the resultant axis in this inevitable plane. The rotations which individual muscles would effect severally, have to be compounded with great nicety into one rotation.

On looking, for instance, directly upwards, the eyeball must rotate about the horizontal diameter of the plane. The superior rectus cannot effect this, because its own axis is inclined by 27° from it. It is, however, so reinforced by a smaller contraction of the inferior oblique that the resultant axis lies in the plane.

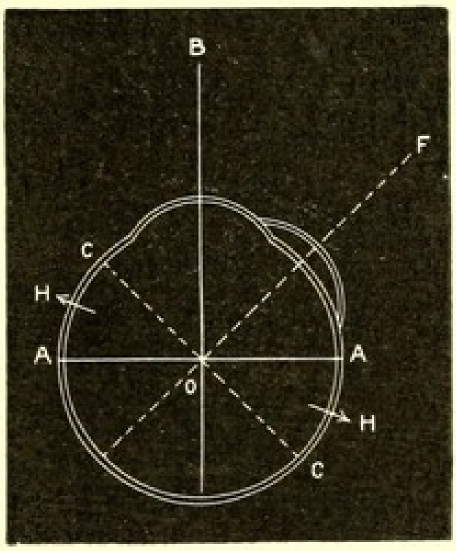
Elevation of the cornea is effected by both of these muscles, but it is a "prime" action of the superior rectus and only a "secondary" action of the inferior oblique.

On the other hand, *intorsion* is a "secondary" action of the superior rectus, and *extorsion* is the "prime" action of the inferior oblique. Since physiological elevation of the eye is always quite free from torsion, the two muscles must contract in such proportion that the intorsion by the one shall exactly counterpoise the extorsion by the other.

For this to be the case, the oblique must contract to a much less extent than the rectus and, in reality, only about three-tenths of the elevation of the eye is due to the inferior oblique, the remaining seven-tenths being due to the superior rectus.

In an exactly similar manner *depression* of the cornea is effected by combined action of the inferior rectus and the superior oblique.

In all this, we are confining ourselves to motions which start *from the primary position.* If the eye be adducted or abducted to start with, the case is, of course, different. Then, as Helmholtz says, the resultant axis no longer lies in the transverse plane of the head, already described, but in a plane which bisects the angle between it, and the plane fixed in the eyeball which originally coincided with the former plane when the eye was in the primary position, but which moves with the eyeball, so as to be ever perpendicular to the line of fixation.




27

To show how in an eye abducted from *B* to *F*, the axis of superduction is not *A A* nor *C C*, but in a mean position (*H H*).

This is shown in Fig. 27, modified from Helmholtz,* where *O B* represents the fixation line in the primary position of the eye.

The equatorial plane *A A* which moves with the eyeball and which passes through the center of motion perpendicularly to the fixation line, takes the position *C C*, when the fixation line is deviated from *O B* to *O F*.

The eye is now in a secondary position, and whatever motion it may make from this position into any other, must be effected by rotating about some diameter of the plane *H H* which bisects the angle between the planes *A A* and *C C*.

There are, of course, an infinite number of diameters in this plane (*H H*) about which rotations are possible, so that it may be called "the plane of the axes of rotation" for that secondary position of the eye.

**Composition of Rotations.**—There is a beautiful and well-known method of representing, in linear measure, the amount of rotation imparted to a rotating body, by simply measuring off along the axis, from the center, a distance proportionate to the rotation ("rotation vector").

There are, of course, two senses in which a body can rotate about any one axis, and it is, therefore, needful to specify in which sense the rotation occurs. This is easily done, for since there are two directions in which we can measure along the axis from the center, we can choose one direction to represent rotation in one sense, and the other direction to represent rotation in the opposite sense.

* Physiologik. Optik.," p. 624.

By convention, we imagine ourselves to stand at the center and look along the axis in that direction which makes the motion appear to us like the hands of a watch or the motion of a right-handed screw.

By a single measured line, therefore, we can record no fewer than three quantities :

(1) The *axis* of rotation, by the direction of the line ;

(2) The *amount* of the rotation, by the length of the line ; and

(3) The *sense* of the rotation, by the direction from the center in which the line is drawn.

We may choose any units we please. Suppose, for instance, we decide to represent degrees by millimeters, then 10 millimeters measured along a direct line means 10° of rotation about that line as axis, and in the same sense as that of a screw being screwed along the direction of measurement. We have only to seize the line at its origin, and *screw*, to understand the sense in which the rotation occurs.

We may compound rotations, therefore, or resolve them as we please, on the same principle as the parallelogram of forces.

**Dynamics of the Eye.**—In theory the dynamics of the eye are exceedingly simple, since the resistances are elastic (and conform, no doubt, to Hooke's law, "*Ut tensio sic vis*"), the forces are tangential, and the lines of the forces may with little error be reckoned as equally distant from the center of motion, so that the moments of the forces are proportional to the forces themselves. The "moment" of a force about a point is the importance of that force as regards balancing or producing rotation about that point. The greater the distance of the line of force from the point, the greater is the moment of the force.

**Forces only Estimated by Results.**—The resistances to rotations of the eyeball are no doubt greater about some axes than about others, and since we cannot calculate this element, we are driven to study the forces as if measured only by the rotations they produce. Instead of compounding *forces* we are obliged to compound *rotations*, for the forces are unknown quantities to us, while the rotations can be investigated to a high degree of accuracy by the behavior of double images and after-images.

Fig. 28 illustrates the composition of rotations in a rotating body whose center is at *o*. The arrowheads on the lines *o a*, *o b* represent the directions in which the lines are measured, and therefore the sense of the rotation which takes place about each as axis and which is the same as that of an ordinary right-handed screw screwed in the direction of the arrow.

Thus the line *o a* represents a rotation proportionate to the length *o a*, and about *o a* as axis, in the sense of a screw driven from *o* to *a*. The line *o b* represents a smaller rotation, since it is a shorter line, about *o b* as axis and in the same sense as a screw driven from *o* to *b*.

When two forces, capable when acting singly of producing these respective rotations, are impressed upon a body simulta-

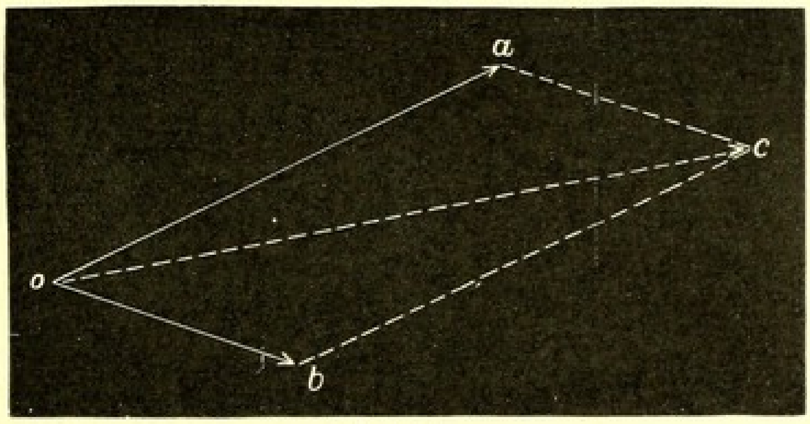



**Fig. 28**
Composition of Rotations

neously, the rotation which results is represented by the diagonal *o c* of the parallelogram *o a c b* completed by drawing *b c* and *a c* parallel respectively to *o a* and *o b*.

The resulting rotation, therefore, is about the axis *o c*, proportional to the length *o c*, and in the same sense as the rotation of a screw driven from *o* to *c*.

The reason for this actual composition of the rotation is as follows : If the body were only subjected to one of the rotations *o a* or *o b*, any point in it would move over a distance proportional, firstly, to the amount of rotation, and, secondly, to its distance from the axis of rotation ; just as the rim of a wheel travels farther than the hub during a given rotation, in proportion to its distance from the axle. When the rotations *o a* and *o b* take place simultaneously, points which lie between their axes would rise in consequence of one rotation and sink in consequence of the other, and there is a line of points (*o c*) so situated that the rising and sinking exactly neutralize each other. The distance of each point in this line from the two axes is inversely proportional to the amount of rotation about the axes, so that the faster rotation of the body as a whole about one axis is compensated for in the case of the point under consideration by its greater distance from the other axis. These points, therefore, all remain stationary and form the new axis of rotation. All points which lie to the $a$ side of it are depressed, because of their distance from $o\ b$ being too great to be compensated for by the greater rotation $o\ a$ ; while points to the $b$ side of $o\ c$ are elevated for the contrary reason.

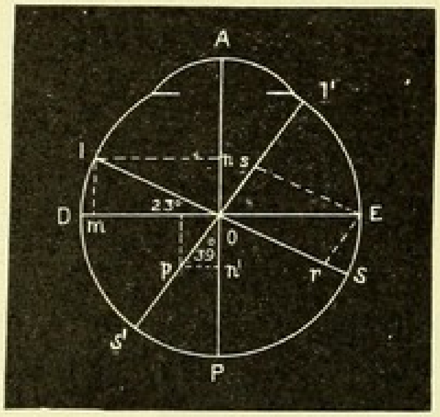



**Fig. 29**
Horizontal Section of a *Right* Eye

Now let us apply these principles to the eyeball. Let Fig. 29 represent a horizontal section of the eye, where $A$ is the anterior pole of the eyeball and $P$ the posterior pole, so that $A\ P$ is the optic axis. The line $D\ E$ is the transverse axis ; $I\ S$ is the axis of rotation for the superior and inferior recti, and $I'\ S'$ is the axis of rotation for the obliques.

A measured quantity ( $O\ r$) along the line $O\ S$ from $O$ as origin, indicates a measured rotation of the globe in the sense of a screw proceeding from $O$ to $S$. This rotation elevates the cornea and is such as would be effected by the superior rectus acting, were it possible, alone. Similarly, any measured quantity ( $O\ s$) from $O$ towards $I'$ specifies a proportionate rotation by the inferior oblique, which also elevates the cornea, since the sense of rotation is that of a screw passing from $O$ to $I'$.

These rotations ( $O\ r$ and $O\ s$), when they occur simultaneously, are compounded into the single rotation $O\ E$, which takes place about an axis in Listing's plane.

Now, as in Fig. 30, let us drop a perpendicular from $A$, the center of the cornea, upon the axis of the superior and inferior recti ( $I\ S$). What have we? The vertical plane passing through this line is the plane of motion for the center of the cornea during isolated action of either the superior or inferior rectus. The anterior pole of the eye under these conditions describes a circle in this plane, which we might call the *corneal orbit* for these muscles, since it is the path in which the center of the cornea travels under their guidance. (See Fig. 30).

A plane, therefore, passing through $A$ perpendicularly to the axis $I\ S$ is the *plane of the corneal orbit* during rotations about that axis ; and we see at once that in whichever sense such rotation takes place, it must necessarily *adduct* the cornea, as well as elevate or depress it.

In precisely the same way a perpendicular may be dropped from the center of the cornea (*A*) upon the axis of the obliques (*I′ S′*) : the vertical plane passing through this line is the *plane of the corneal orbit* during rotations about that axis, at once indicating that abduction of the cornea is a result of such rotations whether they are produced by isolated contraction or isolated paralysis of either oblique, if the usually accepted view is correct that the obliques have a common horizontal axis.

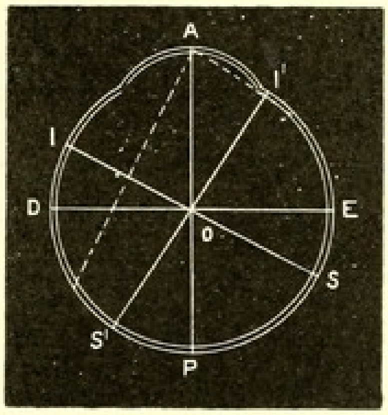



**Fig. 30**

Horizontal section of a *right* eye. The longer dotted line from *A* indicates the vertical plane, to which the motions of the anterior pole of the eye are confined under the guidance of the Sup. and Inf. Recti. The shorter dotted line indicates the same for the Obliques.

**Resolution of Rotations.**—Next, let us see how to resolve rotations due to individual muscles.

Take the inferior rectus as an example, and in Fig. 29 let the distance *O I* represent the maximum rotation it can effect. Drop perpendiculars from *I* upon the transverse axis *D E* and the optic axis *A P*; these perpendiculars cut off distances from *O* along these axes which represent the component depression and torsion respectively.

Since thus *O m* represents the depression of the cornea and *O n* its torsion, we see at once that depression is the prime action of the muscle. The torsion occurs in the same sense as in a screw passing from *O* to *n*, so that it is extorsion.

The lengths of the lines *O n* and *O m* are easily found ; for the proportion which they each bear to *O I* is simply that of the cosine of the angle included between each and *O I*, or, what comes to the same thing, of the sine, and the cosine of *I O D*.

Suppose, for instance, we take the obliquity of the axis of the superior and inferior recti to be 27° from the transverse axis, the component *O m* will be .89, *i. e.*, less than nine-tenths ; and the component *O n* will be .45, *i. e.*, about nine-twentieths of the whole rotation *O I*.

The torsion, therefore, is only about a half of the elevation.

**Co-ordination.**—Let us now see how much rotation the superior oblique must effect in order to be a perfect associate of the inferior rectus (Fig. 29). Clearly, if subduction is to be unaccompanied by torsion, the extorsion *O n* must be counterbalanced by an equal intorsion $O\,n'$. After marking off $O\,n'$, therefore, equal to $O\,n$ but in the opposite direction from $O$, erect a perpendicular at $n'$ to cut off along $O\,S'$ (the axis of the obliques) a distance $O\,p$, which shows the exact proportion of intervention required from the superior oblique muscle, its rotation being resolved into a torsional component ($O\,n'$) which balances the torsional compound of the rectus ($O\,n$), and a subducting component equal to $n'\,p$, which supplements the subducting effect of the rectus. Indeed, the lengths $O\,m$ and $n'\,p$ exactly represent the relative proportion of pure subduction due respectively to the inferior rectus and superior oblique. The latter is scarcely more than two-fifths of the former.*

**Effect of Horizontal Displacement.**—When the eye to start with is ab- or adducted, the proportions are different. We imagine the muscular axes ($S\,I$ and $S'\,I'$) to remain fixed in space (though they do not do so absolutely), and the visual $A\,P$ and $D\,E$ to move with the eye. In abduction, the transverse axis of the eyeball approaches the axis of the superior and inferior recti.

With 27° of abduction, therefore, the torsional component of the superior and inferior recti ceases, while it would reach its maximum were it possible for the eye to rotate in 63°. Conversely, their vertical effect is theoretically greatest with abduction of 27°, becoming nil with hypothetical adduction of 63°.

The torsional effect of the obliques is greatest theoretically† with abduction of about 39° and nil with adduction of about 51°, since in the former case the axis of rotation ($S'\,I'$) coincides with the optic axis ($A\,P$) and in the latter is perpendicular to it. Exactly the opposite is true of their elevating power, which is nil with abduction of 39° and greatest with adduction of 51°.

Though these calculations are at best only approximately true, we can by their aid determine with more or less approach to truth the provinces of the motor field over which different muscles hold chief sway, or sway of a special kind. A chart of the motor field on this principle was attempted by Duane.

The only reliable way of constructing an exact chart of these provinces is by very careful examination and measurement of the motor field in cases of isolated paralysis, since there is some reason to believe that synthetical calculations are only true in a certain measure owing to the influence of Tenon's capsule, that measure being greatest near the primary position and less with increasing departure from it.

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* $n'\,p = O\,m$ Tan. 27°, Tan. 39°.

† The reason I use the word so freely in this section is because I suspect the muscular axes do not remain quite so stationary as is supposed.

The right-hand side of Fig. 29 (where we come to deal with the superior rectus and inferior oblique) shows that to resolve any given superduction of the eye, such as *O E*, we need only complete the parallelogram, of which that line is a diagonal, by drawing *E r* and *R s* parallel respectively to the axis of the recti and the axis of the obliques. Then the dimensions *O r* and *O s* show the component rotations effected by the rectus and its associated oblique. They are proportional to the sines of 51° and 27° and, therefore, about 17 to 10.

It is true that isolated paralysis of the superior oblique is common. The double images therefrom indicate sometimes abduction of the cornea, but far more frequently adduction. Moreover, the occasional abduction is most likely explainable, on Mauthner's hypothesis, by the liberation of a previously-existing latent squint, or tendency of the eyes to diverge (exophoria) when not engaged in single vision, from slack action of the converging innervation.* If this explanation of Mauthner's be true and adduction be the characteristic effect of this paralysis during the primary position of the sound eye, then the axis for the muscle must be tipped up above the horizontal plane at its outer end and dip below it at its inner end, as shown in Fig. 31.

Even then, adduction would only occur during a moderate paralytic displacement of the eye, and would give place to abduction if it exceeded a certain amount, which it would be quite easy to assign were the exact tilt of the axis known.

In fact, as soon as the depression of the eye were to become twice as great as the tilt of the axis, adduction would begin to give place to abduction, provided the center of motion of the eye be fixed.

**Paralytic Exophthalmos.**—It should not be forgotten that since the four recti tend to draw the eyeball back into the orbit (and balance thus the tensions in the expansion from Tenon's capsule to the orbit with its check ligaments, and the oblique muscles, all of which tend to draw the eye forwards, assisted by the elastic resistance of the retro-orbital fat) it is more than likely that pronounced paralysis of a rectus, when physiological tone is lost, allows the center of motion to advance, and thus the eyeball to be translated forward as well as rotated. This, however, would only introduce a source of error into any quantitative calculation, for it would not alter the principles: the paralytic rotation of the globe would be the same in kind as if no translation occurred, but less in amount.

It would, indeed, occur about an axis, exactly the same in direction as if there were no translation, but which instead of passing through the center

* Perfect orthophoria (by which I mean orthophoria maintained if one eye be excluded for a week) is not found in one of a thousand: it is this which makes the horizontal element in paralysis so uncertain.

of motion would lie to the opposite side of it from the paralyzed muscle, so as no longer to be a diameter of the globe. The rotation about this new eccentric axis, however, would be resolvable into an advance of the center of motion and a rotation about it, the latter being the same in kind, but less in degree than if there were no translation. The greater the translation the less the rotation. The translation in itself is of no clinical account, since it does not affect the diplopia directly, but only indirectly by lessening the amount of rotation.

**Model with Tilted Axes.**—On an india-rubber ball, like Professor Landolt's, I have represented, as in Fig. 31, the paths pursued by the center of the cornea during contraction or paralysis of isolated muscles whose axes of rotation are tilted to the horizon. Since there are four

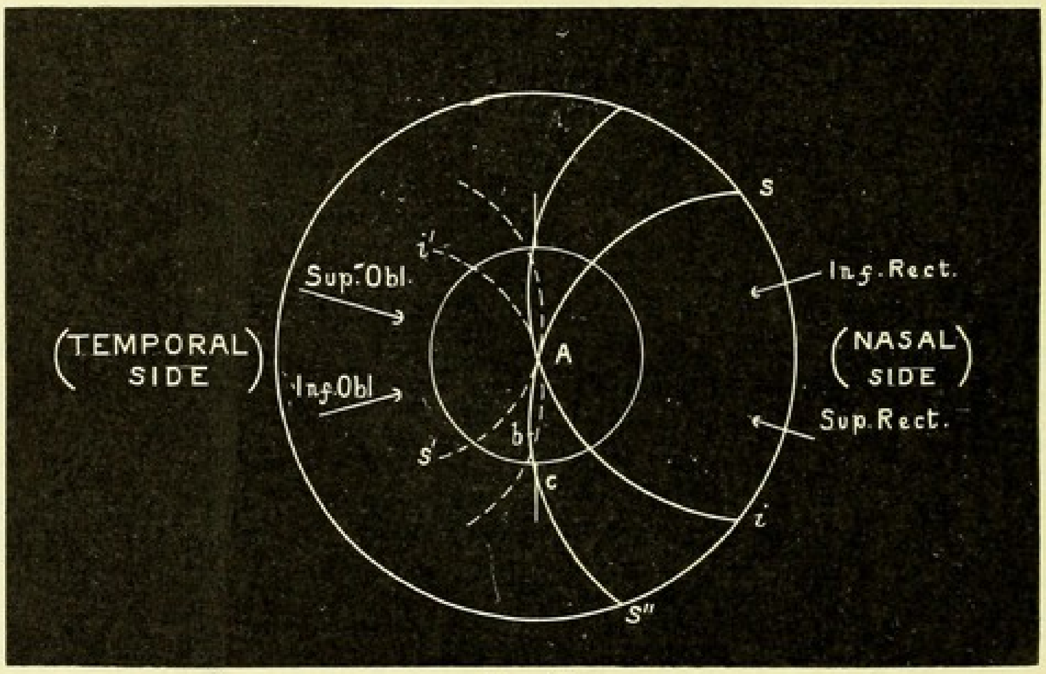


**Fig. 31**

An india-rubber ball, marked so as to show the Paths of the Cornea during Contraction and Paralysis of the Muscles, if their Axes are tilted (the tilt being purposely exaggerated).

muscles concerned, none of which have coincident axes, there must be four corresponding paths (or orbits) for the center of the cornea. Since the axes are not horizontal, the muscular planes, to which they are invariably perpendiculars, cannot be vertical planes, neither can the planes of the corneal orbits, for they are parallel to the muscular planes.

**Construction.**—We may, therefore, after deciding how much to tilt the axes in a model (*e. g.*, an india-rubber ball), still follow Professor Landolt's plan of placing one leg of a pair of compasses on the extremity of each axis in turn, and the other leg on the center of the cornea to describe a circle with the latter. These circles are the four corneal orbits for the respective muscles.

**Differences.**—In a horizontal-axis model there are only two corneal orbits, each common to a pair of muscles, and it will be seen from Fig. 23 that neither orbit transgresses the vertical meridian : though both touch it at the corneal center, they keep strictly to their own sides, so that, in the primary position, adduction is the only result demonstrable by the model of either contraction or paralysis of the recti : and abduction for the obliques. In Fig. 31, however, each orbit crosses the vertical meridian.

It may be well to explain that the model does not represent the actual globe of the eye, but an infinitely thin sphere immediately surrounding it and fixed in space, so that the center of the cornea, in its motions, describes these paths upon it.

The vertical meridian of this sphere coincides during the primary position of the eye, with the vertical meridian of the cornea, but is fixed while that moves. The cornea, when its center is found to the usual nasal side of this fixed vertical meridian, is adducted, when to its temporal side abducted. From the fact that each corneal orbit lies in part to one side and in part to the other, it is evident that both adduction and abduction occur with motions about each axis. Each rectus (superior and inferior) *on contracting*, adducts the eye, and each oblique abducts it.

The semi-orbit *A s* is that for contraction of the superior rectus, *A i* for the inferior, and both are entirely to the nasal side of the fixed vertical meridian, showing these muscles to be adductors. Moreover, since these orbits form an angle at the vertical meridian at the anterior pole instead of touching it by a continuous curve, as in Fig. 23, adduction is more marked and commences at once in such a way as not merely to be an incident of the motion of the cornea, but to be due in part to true rotation of the globe about its vertical axis, which we have shown cannot occur if the axes of rotation for the muscular contractions are not tilted to the horizontal, since horizontal rotations cannot have vertical components.

The more tilted the axes are, the greater are the vertical components of their rotations.

The same may be said, *mutatis mutandis*, of the orbits *A s′*, *A i′* for the obliques, which show the eye to be more vigorously abducted by contractions of these muscles than in Fig. 23.

**Paralytic Semi-Orbits.**—When we come to consider *paralytic* rotations, the two figures are in contrast.

What we may call the "paralytic" part of each orbit lies to the opposite side of the meridian from the "contractile" part, for a certain distance, and shows that paralysis of a muscle causes, at first, the opposite horizontal diplopia from its contraction. Thus the arc *A s″* is the paralytic arc for the superior rectus, being continuous with its (already considered) contractile arc *A s*.

It crosses the meridian at *A*, showing that the slightest paralysis causes abduction at once, which increases to its maximum at *b* when the depression of the eye is equal to the tilt of the axis from the horizon, and then as the paralytic rotation becomes greater the abduction lessens, till the orbit again crosses the meridian at *c*, thereafter to give place to adduction. This crossing of the meridian occurs when the depression of the eye is twice as great as the tilt of the axis, for *c* is twice as distant from the horizontal meridian of the fixed sphere as the extremity of the axis.

I have carefully said "as the paralytic *rotation* becomes greater" instead of saying "as the paralysis increases," because the paralytic rotation does not necessarily keep pace with the increase of paralysis, as we have already seen, the latter perhaps expending its effect to some extent on translation of the globe forwards.

When this is the case, what relation exists between translation and rotation? It will not do to compound them according to ordinary physical composition, for the translation is not something *added* to the rotation. The simplest way would probably be to look upon the pathological yielding of the muscle under remaining tension as represented by a definite linear quantity of lengthening. Without translation, this linear quantity, curved round the surface of the globe into a circular arc, measures the angle of paralytic rotation, being the arc which subtends that angle at the center of motion. When translation occurs, this arc of rotation is shortened by a linear quantity equal to the amount of translation.

Thus, if the lengthening of the muscle be 3 mm., the angle of rotation, without translation, would be an angle subtended by an arc of 3 mm., but with 1 mm. of translation it would be an angle subtended by an arc of 2 mm.

## CHAPTER V

### Conjugation of the Two Eyes

To the best of our knowledge, every innervation of the ocular muscles is conjugate. It is impossible for a nervous impulse to descend to the ocular muscles without being equally divided between the two eyes. In consequence of this the two eyes work together, to borrow Hering's expression, as one organ.

It will be seen, therefore, that the "centrifugal" impulses to the eyeballs answer completely to the "centripetal" arrangements of vision. Homonymous halves of the two retinæ convey impressions to the occipital lobe of the same side. An object, for instance, which lies in front and to the left throws its images on the right half of each retina. If the images fall on corresponding points they are blended into one in the visual center into the right visual lobe. In that case, if attention be directed to the object, both eyes move equally and simultaneously as one organ, so as to receive the images of the object on the two maculæ and inspect it by direct vision. More often than not, however, the object is so situated at first that its images do not fall on strictly corresponding points. Then, simultaneously with the conjugate lateral movement, an adjustment of the convergence takes place, in an equally conjugate manner, the two movements being compounded into one.

**True Associates.**—Every muscle, therefore, has a yoke-fellow in the other eye. The superior rectus of one eye is associated with the inferior oblique of the other ; and the inferior rectus of one with the superior oblique of the other.

Graefe based this view on the secondary as well as the prime action of the muscles. For example, the elevating power of the right superior rectus is greatest on looking also to the right : and that of the left inferior oblique is likewise greatest on looking also to the right. On looking to the left, the elevating power of both decreases, and the torsion of both increases. Moreover, their torsion is in the same sense. These muscles, therefore, work together more harmoniously than either could do with any other work-fellow.

As a matter of fact, however, in the voluntary motions of the eyes this pair never works alone, without the other pair of associates, the left superior rectus and the right inferior oblique, as we learn from the study of secondary torsion (Chapter II).

Graefe suggested that the best operative treatment for paralysis of a muscle would be tenotomy of its associate in the other eye. Thus, for a faulty right superior oblique, he would think of tenotomy of the left inferior rectus, from the consideration that if both associates are weakened a stronger impulse is all that is needed to remedy the defect in both. There are weak points in this practice, excellent as the reasoning is, one being that the proportion of elevation effected by the oblique is much less than that effected by the rectus, and the other that tenotomy does not really weaken a muscle *much*, but chiefly acts by altering the position and shortening the length of its arc of contact. It does weaken it a little, however, indirectly, owing to the lengthening of the check ligament, and to that extent it keeps company with the paralysis. Practically, the operation is rarely advisable, unless the diplopia is considerable while the sound eye is in the primary position.

**Spasm of Single Muscles.**—It is rare to meet with an unimpeachable example of those cases, described by others, in which there is true idiopathic spasm of an isolated muscle. It is possible that ocular muscles may be subject to "cramp," like that in the calf of the leg, but I have not met with it. Were it to occur in any but the internal rectus, it could easily be diagnosed. Its characters would be: (*a*) Sudden, extreme and temporary deviation of one eye. (*b*) Normal motions showing no paretic muscle in the other eye. (*c*) Absence of marked heterophoria in the intervals between the attacks, as tested, by occlusion or the glass rod. This is the most important point in the diagnosis, for sudden deviation of an eye may be due to liberation of a previously-existing high degree of latent squint and, unless paralytic, is always due to this. Spasm of the internal rectus is often simulated by spasm of convergence, and since the latter is always immensely more probable, it should be given the benefit of any doubt. (*d*) No other paretic muscle in the affected eye discoverable after the attack, the nervous energy intended for which may have overflowed into another, for "secondary deviation" can be a monocular as well as a binocular affection. (*e*) During pure spasm of a single muscle there would be a temporary loss of concomitancy, causing the squint to be greater on looking in some directions than in others.

In *chorea* slight irregular contractions of the ocular muscles are said to sometimes take place, as evidenced by brief diplopia.

In *meningitis* and other irritative affections of the base of the brain, irritation of the nerve trunks may cause spasm of individual muscles, though far more frequently paresis, or both. It is comparable to the rigidity that occurs in the limbs (Gowers).

Crampy or epileptiform spasms of single muscles have been recorded by Hock, Gowers and Duane, in some cases occurring when the eye was moved into the field of the muscle, in others without any exciting movement of the eye.

*Hysteria* is said to never affect single muscles.

I have dwelt at this length upon muscular spasm, in spite of its extreme rarity, because it looks like an exception to the rule of "conjugation," though not really so, since the pathological does not disprove the physiological.

**Conjugate Innervations.**—The number of conjugate innervations is, at present, unknown. Five have long been recognized: of which one elevates both corneæ, another depresses them, a third turns both to the right, and a fourth both to the left. The fifth is the converging innervation.

Of the conjugate innervations of the eyes these five only are voluntary. They are those for the four parallel movements of

(1) Binocular elevation;

(2) Binocular depression;

(3) Binocular dextroduction;

(4) Binocular lævoduction; and that for the totally distinct act of

(5) Convergence.

Even parallel motions are, however, I find extremely difficult to effect if the eyelids be kept closed, though they can be brought about by the greatest ease in perfect darkness if the eyelids be opened. The act of convergence is not so easy to effect in darkness as parallel movements, being rather more dependent than they on visual reflex government in ordinary life. It is most easily effected by thinking of a near object, and it probably has its cortical seat only in the occipital lobes (calcarine fissure). Besides these five innervations, which are more or less under voluntary control, there are two which trim the torsion of the two eyes to the right and left simultaneously and which may, therefore, be described as

(6) Binocular dextrotorsion, and

(7) Binocular lævotorsion

These innervations are absolutely involuntary. We know of their existence from physiological experiments, clinical observations and the phenomena of rotational nystagmus.

Others must have noticed what I have sometimes observed, viz., that after a careful correction of astigmatism the patient may come back needing a slight alteration of *both* cylinders by an equal amount to either the right or left, showing that a slight preponderance of one of the innervations for conjugate dextroduction or lævoduction has occurred during the interval.

Moreover, in paresis of an oblique muscle, if it happens to belong to the best eye, it is not very rare to find the tilted image transferred to the unparalyzed eye, from corrective activity of one of these innervations.

I have recently seen a striking illustration of the same kind of transference in a doctor, whose left eye had been blind for ten years with ripe cataract, the vision of the right eye being rather poor. After extraction of the cataract, vision was wholly transferred to the left eye and vertical objects appeared slanting to the left, proving that the left eye had become extorted during its blind period. This extorsion, however, soon rectified itself, but in doing so intorted the right eye, as shown by the fact that on occluding the left, objects viewed by the right appeared slanting to the left. The correction, therefore, had been effected by a conjugate innervation, viz., that of binocular dextroduction. This correction did not take place once for all, but ceased as soon as ordinary objects no longer engaged the attention, so as to call for it, as shown by experiments with the glass rod.

It is not scientific to speak of these corrections as effected by the obliques. This is well illustrated by rotational nystagmus, in which the two eyes, while experiencing simultaneous wheel-movement, strictly maintain their visual axes at the same horizontal level, which could not be if the obliques only were the active agents : for if they were, we should find that during double-wheel movement, say, to the right (binocular dextrotorsion) the superior oblique of the left eye would depress the left cornea, and the inferior oblique of the right eye would elevate the right cornea.

The obliques could not of themselves get rid of their subordinate movements.

Again, Javal showed, by the observation of astigmatic correction, that when we slope the head towards either shoulder the principal meridians of the two retinæ no longer remain strictly parallel with the median plane of the head, but lag behind it a little.; their inclination from the true vertical becoming slightly less than that of the head, though they are still parallel with each other, an observation verified by Helmholtz, with after-images, in a very beautiful way. We have, therefore, abundant evidence of the existence of these two innervations.

It is extremely probable that there are innervations for regulating the parallelism of the vertical meridians of the retina with each other, namely, one for

(8) Binocular intorsion, and one for

(9) Binocular extorsion.

There is reason to believe that if only one of these exist, it is probably that for binocular intorsion, and that binocular extorsion is effected by its relaxation or inhibition; for (though I speak from general impressions only, and not from statistics) my experience hitherto has appeared to show that want of general tone manifests itself rather by a tendency to binocular extorsion than by intorsion. Since the same loss of tone occasions relaxation of the converging innervation, it may be that *binocular intorsion* plays the same part with respect to the *wheel*-movement of the eyes as the *converging* innervation plays with reference to the visual *axes*. If this be so, intorsion should be designated as a plus quantity, just as positive convergence is a plus quantity, and extorsion would be analogous to divergence.

The weak point in the demonstration of innervations 8 and 9 is that no case of nystagmus betraying these motions has yet been recorded, but a great many physiological facts appear to make at least one of them a necessity.

Of some other innervations we have no positive proof. There may very likely be one for

(10) Divergence. But until its existence be demonstrated, it is safe to assume that its place is taken by relaxation and inhibition of the converging center.

Finally, there may be one or two feeble innervations for preserving the two visual axes in the "visual plane" (*i. e.*, the plane common to the fixation point and the centers of motion of the two eyeballs) and by means of which we can overcome a weak vertical prism before one eye, or in some cases correct a high degree of congenital hyperphoria. Lesion of the middle peduncle of the cerebellum has caused movement upwards of one eye and downwards of the other, and this affords a slight confirmation of these innervations, which would be

(11) One for raising the right visual axis above the left, and

(12) Another for raising the left visual axis above the right.

The cortical seat of the conjugate innervations of the eyes has been supposed to be in several positions from time to time, but the most reliable observations reduce their location to the hinder part of the mid frontal convolution and the median surface of the occipital lobes. It is still doubtful whether the occipital centers avail for visual reflex movements only or for voluntary also; but most likely the voluntary movements proceed from the mid frontal convolution, stimulation of which causes movements of the head and eyes toward the opposite side of the body. The inner surface of each occipital lobe receives centripital impulses from the same named halves of the two retinæ and since objects seen by these halves lie in the opposite side of the field we should expect stimulation of, say, the right cuneus, to turn both eyes to the left; and so, in fact, it has been found to do by experiment. Schafer and Munk not only found this, but also that stimulation of the fore part of the visual center caused depression of the eyes and of the hinder part, elevation. They also found one neutral point, stimulation of which caused either no motion or one of convergence only.

The movements of ordinary life are partly voluntary and partly reflex. When the voluntary part is impaired the reflex element may preponderate, as in the following interesting patient of the author's, where the conditions were the exactly opposite to what sometimes obtains in paralysis agitans. In that disease the movements of the head are slow compared with that of the eyes, so that when the eyes glance at a new object, the head slowly follows after them. The reverse took place in this case, the head turning quickly to any new object while the eyes remained fixed on the last, and only slowly regained the new position of the head.

*Accoucheur* reports that "the mother's labor was very tedious . . . . had to be completed with long forceps after great difficulty, the forceps having of necessity compressed the child's head for a very considerable time. The child's breathing was established with difficulty after its birth, but it continued to breathe feebly for at least a week, and never cried. There was also entire loss of the power of deglutition, and the child seemed as if it might die at any moment. It gradually, however, regained strength and the power of swallowing to some extent. I may mention that the child was a well-nourished, healthy-looking child at birth, and that the marks of the forceps showed that one blade had been applied over the ear and the other over the opposite cheek and temporal bone."

*Her father* reports that for six months or more she had to be carried about with her head on a pillow, and was only taught to eat, *i. e.*, to masticate, by imitation; she was about three years old when she began to do this. Her orientation, or sense of the direction in which objects lay, was fallacious. To correct this defect in the faculty of projection, her mother had to teach her to direct her hand to an object to pick it up by scattering pins on the floor, and training her to put her hand in the right direction for each.

*The author* first saw her at the age of twenty. She was well developed, intelligent, had quite recovered the power of swallowing, but still cannot masticate, working the food with her tongue instead. She has spasmodic contraction of the frontalis muscles, alternating with contraction of the orbiculares palpebrarum. The ocular movements are effected downwards without difficulty, but upwards they are only about two-thirds of the normal. On telling her, however, to look to the right, she contorts her mouth, works her frontalis and orbicularis muscles violently and, as often as not, begins by looking a little to the left, as if finding great difficulty in directing the impulse into the right channel; at last she succeeds in turning the eyes completely in the direction asked for, though not smoothly. On telling her to look to the left, the same kind of thing happens. It is easier for her to follow a finger to the right or left than to look from one finger to another; in each case the chief difficulty met with is in crossing the middle line, a long halt and much working of the eyebrows being met with. In a railway train she cannot take in what is passing. To observe an object she has to keep moving her head instead of her eyes. On asking her to turn round to look at a person behind her, the appearance is most remarkable: the head goes round with the body, but the eyes remain as long as they possibly can, till actually carried round by the canthi ; she is then giddy for a moment. She never has diplopia and never feels giddy except in the act of turning round.

Here, then, is a case in which there is no defect of the ocular muscles themselves, but extreme awkwardness in effecting voluntary movements of the eyes to the right and left ; though the reflex control of this function is not impaired. The contortions of the face are merely the overflow of misdirected nervous energy.

**Conjugate Paralyses.**—The conjugate "elevating" and "depressing" innervations are sometimes impaired by disease, so that both eyes show defective movement either upwards or downwards, without diplopia or any sign of muscular paresis. The exact cerebral localization of their cortical centers is uncertain, however.

The horizontal conjugate innervations, which impart lateral motions to both eyes, to right and to left, are also sometimes impaired by disease. One of these innervations causes conjugate dextroduction, and the other conjugate lævoduction. When either is defective, the field of fixation on the same side is proportionately restricted, *i. e.*, the eyes cannot be turned to that side, and yet there is no diplopia or sign of individual muscles being affected.

The dextroducting innervation acts equally upon the right external rectus and the left internal rectus. The lævoducting innervation acts equally upon the left external rectus and the right internal rectus. It will be seen, therefore, that the arrangement is very much like that of the reins of a pair of horses (Gowers).

In glancing from right to left, or *vice versa*, it is evident that there must be a momentary median position of the eyes in which the work is transferred from one innervation to the other. Indeed, in some patients a distinct falter is observed in this movement if the eyes be made to follow the finger from right to left, which, if marked, may be regarded as a sign of defective co-ordination.

Each of these innervations for right and left motion is supposed to arise in the cortex of the *opposite hemisphere*, and *cross* to the superior olivary nucleus of the same side ; thence to the nucleus of the sixth nerve on the same side, after which the path divides into two, one along the sixth nerve to the external rectus of the same side, and the other through the nucleus of the opposite third nerve (perhaps reached by the posterior longitudinal bundle) to the opposite internal rectus. Any interference with this innervation, therefore, must be due to some defect higher up than the division of its path into two : it must be either in or above the sixth nucleus.

**Convergence.**—Were these four innervations the only ones to control the eyes, their axes of fixation would be ever parallel. A fifth is necessary to converge the eyes upon near objects, and it is found to have quite an individuality of its own.

It also affects both eyes equally, and though its cortico-nuclear path is not well ascertained, its nucleo-muscular path is well known, since it certainly passes through the third nerve nuclei and divides into two paths, each of which courses down the branch of the third nerve, which supplies the internal rectus of its own side.

Entire absence of the converging innervation is met with, though very rarely; considerable defects are not so very uncommon, and trifling ones are exceedingly common; in all of which the innervations previously described may be perfect.

**Monocular Motion.**—Though all the innervations of the eyes are equally divided between the two members, it does not follow that motion of one eye necessitates motion of the other.

Fig. 32. for instance, which is borrowed, with a slight modification, from Hering, shows how one may remain quite stationary while the other moves, without in the least impeaching the rule of equally divided innervations.

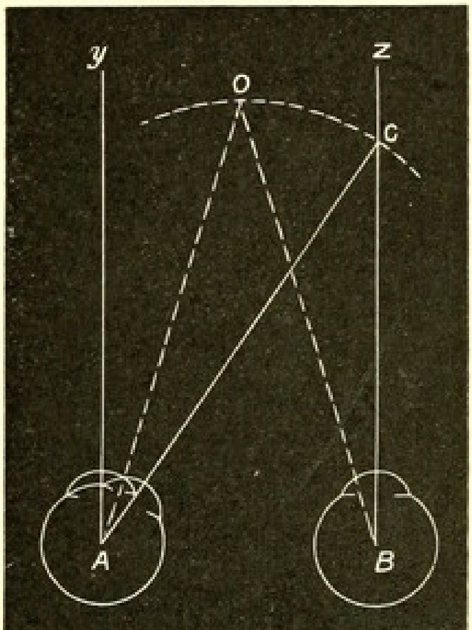

Fig. 32

Modified from Hering, to illustrate Conjugation. In looking at *c* the eyes converge as if for *o*, and are as if deflected from *o* to *c*.

The lines *y* and *z* represent parallel visual axes, while the eyes are looking straight forwards at some very distant object. Let the attention be now diverted to a near object (*c*) lying in the line of the right visual axis *z*, so that the right eye has no motion to make in looking at it, but the left eye has to sweep through the angle *y A c*. Hering has shown that half the motion of the left eye (*y A o*) is due to the converging innervation, and the remaining half (*o A c*) to the innervation which turns both eyes to the right, and that while the two innervations conspire in the case of the left eye, they exactly counteract each other in that of the right. The left internal rectus is stimulated by both, and the left external rectus by neither; whereas, the right internal rectus is stimulated by one, and the right external also by one. Convergence, therefore, brings both eyes as if to *o*, through the equal angles *y A o* and *z B o*, and dextroduction moves them as if from *o* to *c*, through the equal angles *o A c* and *o B c*; not, of course, that they act in succession but simultaneously, so that every increment of converging force is instantaneously prevented from moving the right eye by an equal increment of dextroducting force. The mechanism is wonderfully perfect.

It may be noticed that in the diagram (Fig. 32), instead of following Hering by making *o c* a horizontal straight line, I have made the point *o* a little farther from the eyes than *c*; for were it not so, the angles would not be equal. They are only equal when they lie in the same circular arc as the centers of motion of the two eyes.

Fig. 33 is to show this, where the circle *A B O c* represents what I have called an "isogonal line,"* or line of equal convergence. All points in the periphery of this circle, when made objects of fixation, require an equal amount of convergence. That explains the dotted line between *c* and *o* in Fig. 32 being in the form of a curve, instead of a straight line.

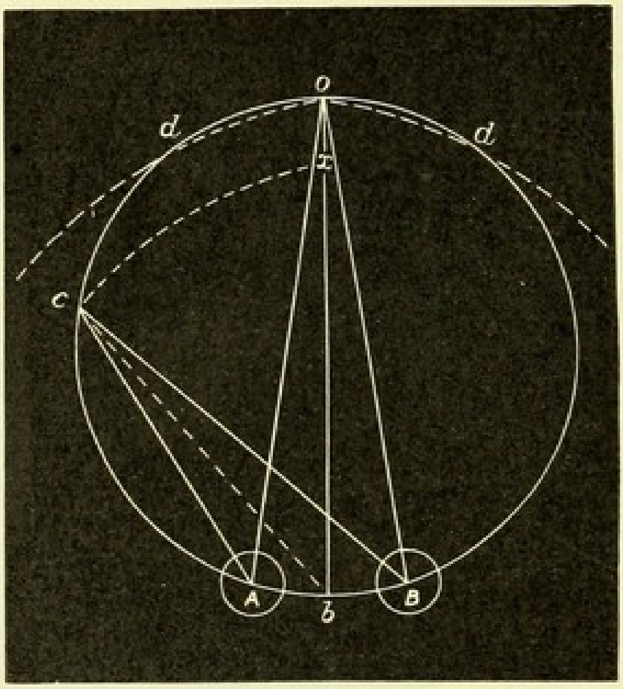


**Fig. 33**

(Syme Fellowship Essay, 1884.) To illustrate the relation between convergence and accommodation in lateral fixation. Looking at *c* requires convergence as if for *O*, and accommodation as if for *x*.

In Fig. 33 it is not only true that the angles of convergence are equal, but in glancing from any one point in the circle to any other, both visual axes traverse equal angles: thus the angles *O B c* and *O A c* are equal. It is the curve, therefore, both of uniform convergences and of equal lateral ductions for the two eyes.

* "Journal of Anat. and Phys.," vol. xxi., p. 581.

It must not be thought that the rules of conjugation, so well investigated by Hering, exist merely in theory ; they are exceedingly well proved.

**Confirmation of the Rules of Conjugation.**—The reader can, if he please, confirm them for himself, by fastening a square black velvet to a thin board, and fixing a tiny piece of white paper, say, 2 mm. square, at its center. Holding the board about 8 inches before the face, look at the tiny piece of paper, and suddenly cover the right eye with a visiting card.

To a keen observer the white spot will now, in most cases, appear to move slowly to the right.* Now here is a remarkable phenomenon : The point of view *seems* to move when not only is it really stationary, but the eye which looks at it and the image it throws upon the retina are stationary also.

That the covering of the right eye does not make the left eye move may be proved by placing a circular piece of paper, half an inch broad, on the velvet screen just where it is lost to view in the blind spot of the left eye, and such that any motion of the eye would make the paper spring at once into view. It will be found that covering the right eye does not make it spring into view : the left eye, therefore, does not move.

What, then, is it that makes the white spot fixed by it *seem* to move?

Simply this, that when the right eye is covered, the necessity for strict convergence ceases, and the converging innervation relaxes a little. Were this all, both eyes would diverge a little, but that would make the left eye deviate as well as the right : to prevent the left eye from moving, every relaxation of convergence is simultaneously compensated for by a corresponding increment of nervous energy from that innervation which turns both eyes to the right. This, while it just counteracts the divergence of the left eye, increases the divergence of the right.

Now, in estimating the position of the white spot on the screen, the mind pays no attention whatever to the behavior of the converging innervation (unless to make the white spot appear to recede to a distance, as Percival experiences when he tries the experiment), but is keenly alive to the slightest output of energy by the other innervation, and judges the gradual evolution of its

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*This experiment is best made, and indeed was originally made, with the visual camera (Chapter XIV).

energy to be due to motion of the white spot, instead of attributing it to its true cause.

This experiment alone would suffice to prove that the muscular sense, in the case of the ocular muscles, is not peripheral but central, since it is the kind and amount of central innervation that determines the judgment of localization in space, not the muscular tension excited by it.

Now, to continue our experiment: After holding the card before the right eye for a full minute, suddenly remove it: two white points appear which run into one, and it will be seen that they *both* move at equal rates to meet each other, so that the previously-slow movement of the first one is rapidly retraced.

Why is this?

It is because the sudden apparition of double images at once awakens the desire to unite them and quickens the converging innervation, which acts on both eyes alike, to do so. The left eye, however, all the time, does not stir (as we can prove, if we wish, by the blind-spot method), for as quickly as its internal rectus experiences the converging stimulus, it loses the previous dextroducting stimulus.

It is the *cessation* of the dextroducting stimulus which in this experiment makes the white point appear to move to the left.

On the other hand, half the corrective movement of the right eye is due to converging impulse, and the other half to the cessation of dextroduction.

The practical perfection of this mechanism is most important in the little details of life.

**Mental Appreciation of Parallel Innervation.**—We have proved that the mind takes the most careful cognizance of the least output of energy by the innervations which cause parallel motions of the eyes. So much is this the case that artists are said to be able to judge more correctly the lateral distance between two objects by glancing rapidly from one to the other than by any other visual method.

**Mental Appreciation of Converging Innervation.**—What now about the converging innervation? Does the mind take no cognizance of it? Yes, but in a totally different way. It speaks to the mind *only* of the *distance* of objects, *not* in the least of the *direction* in which they lie.

Converging impulses affect both eyes equally, and since in looking at near objects, the eyes have to converge more strongly than for remoter ones, the sense of nearness is, *cæteris paribus*, proportionate to the effort put forth

The mental estimate of convergence, however, is not so minutely exact as for parallel motions of the eyes. The reason of this may be that we possess no other means of telling the *direction* of an object than by the parallel innervations of the eyes, but their *distance* is known to us by their apparent size, by atmospheric effects, by perspective, by stereoscopic phenomena, and by the effort of accommodation required ; and (we must also add) our knowledge of the relative position of objects or their surroundings from experience.

**Convergence and Accommodation.**—This leads us naturally to treat (though briefly) of the association between convergence and accommodation. The accommodating innervation affects the two ciliary muscles in just as conjugate a manner as the converging innervation affects the two recti. This is believed to be the case even when the two eyes are congenitally of different refraction ; so we may conclude that the innervations of the eyes are not entirely disposed by habit.

When we look at a very distant object, convergence and accommodation are both nil, and they increase *pari passu* as the object approaches.

This intimate correlation between the two actions is in such perpetual exercise during the waking hours of life that we might naturally wonder at first thoughts whether one single innervation would not have served the purpose of two.

I will content myself here with giving one reason why this could not be, on geometrical grounds, unless all vision were directed to objects in the median plane. Whenever the eyes are turned to the right hand or the left, a differing proportion between convergence and accommodation is necessitated : for slight lateral motions of the eyes, accommodation needs to be relatively increased, but as soon as the motion exceeds a certain limit, the necessity is reversed, and the greatest demand is for convergence.

Let us look at each in turn, and consider :

(*a*) *Accommodation.*—Apart from any connection with convergence, disproportion between accommodative requirements *in the two eyes* respectively is brought about by the slightest deviation of the point of fixation from the median plane, except along one curve only.

Fig. 34 illustrates this when any flat object is looked at, as in reading a book. The prolongations of the visual lines on the distal side of the line *A B* represent the disproportion.

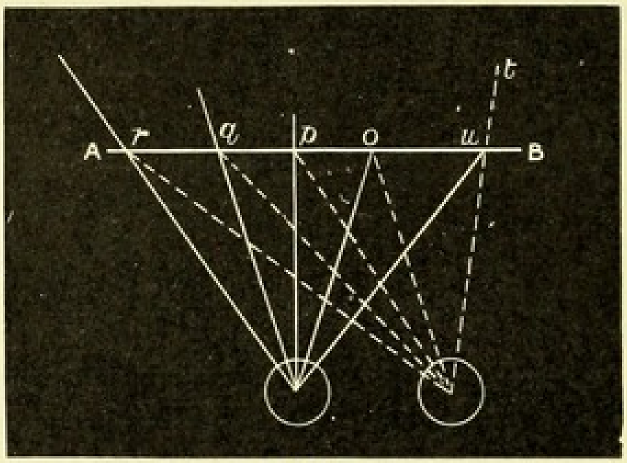


**Fig. 34**

**Shows the different amount of Accommodation called for in the two eyes on lateral fixation**

Thus, when both eyes are looking at *u*, the object is nearer to the right eye than to the left by the distance *t u*, and so on. Every departure of the point of fixation from the middle line lessens the required accommodation in the opposite eye, while at first it increases that of the eye of the same side till the fixation point has traversed a distance *o p* equal to half the interocular distance, after which it falls through a similar interval *p q* to the original amount, and then continuously diminishes.

But the centers for accommodation are so intimately connected that one eye does not normally accommodate more than the other. When variations, therefore, exist either in the refractive power or requirements of the two eyes, "that eye has the bright image which attains it most easily at the expense of the other" (Donders). They do not split the difference; if they did so there would be diffusion circles in each eye.

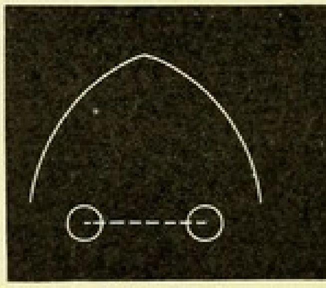

**Fig. 35**

**Line of equal Accommodation**

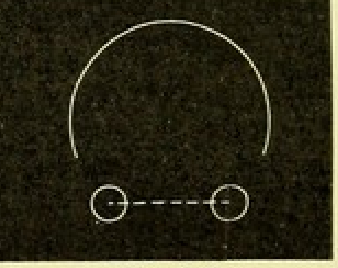

**Fig. 36**

**Line of equal Convergence**

Since accommodation with normal refraction implies positive effort, that eye which is *farthest* from the object and can see it with least effort, determines the accommodation for *both*.

Fig. 35, therefore, represents "the line of equal accommodation" for near vision, made up of two curves, in whatever point of which the object is placed accommodation remains the same. It is composed of two arcs of equal radius, described from the centers of their opposite eyes.*

(*b*) *Convergence.*—Fig. 34 shows that convergence, as well as accommodation, diminishes with oblique vision; but that they do not diminish equally is made clear by the fact that the line of equal convergence (Fig. 36) is not of the same shape as that of equal accommodation (Fig. 35).

The equal-convergence curve in Fig. 36 is part of a circle which passes through the centers of motion of the two eyes (not like the horopter through the nodal points) and possesses these properties:

(1) The angle of convergence is the same whatever point in it is made the point of binocular fixation.

(2) In glancing from any one point in it to any other, both visual axes traverse equal angles; thus in Fig. 33 the angles *O B c* and *O A c* are equal; while, in contrast to this, Fig. 34 shows that in glancing from *o* to *p* or *o* to *q* the left axis passes through a greater angle than the right; as it does, indeed, whatever point is looked at to the left in the straight line *A B*.

(3) The line which bisects the angle of convergence is the one to which (hypothetically) objects upon the maculæ should be mentally referred. Whether, in fact, they are so physiologically, is another question, as we shall see.

The line is obtained by uniting the point of binocular fixation (*c*, in Fig. 33) to the posterior point of the circle (*b*). The position of this posterior point shifts, slightly, of course, with every variation in the size of the circle.

The line *c b* itself is inclined to the median plane by an angle which measures the obliquity of vision, since it is equal to the angle which *each* visual axis has traversed in looking from the anterior point of the circle (*O*) to any other point in it (*c*).

**Curves Applied to Each Other.**—In Fig. 33 the dotted arcs represent the line of equal accommodation, so applied to that of equal convergence as to illustrate the fact already mentioned, that within a certain degree of obliquity of vision the proportion of convergence to accommodation is greater than in the median plane, while for greater obliquity the proportion is less.

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*In *hypermetropia* the line is similar; the reasons for it being so are intensified, since accommodation is a greater effort; but in *myopia* accommodation is negative outside the line which limits the far point, and which is made by drawing each arc from the center of the eye of the *same side*. Since in these cases relaxation is often attended with more effort than accommodation (owing to spasm of the ciliary muscle), the "line of equal accommodation" would be of the same shape as the "far-point line" for some distance within it.

At the points *d d*, where the two lines intersect, the proportion between convergence and accommodation is the same as at *O*; within these points convergence must be relatively increased; outside of them relatively lessened. The distance of each *d* from *O* is always exactly equal to the inter-central distance of the observer.

The same figure shows how, in looking obliquely at any point, the convergence and accommodation required may be compared with that in the median plane. All that is necessary for any given point (*c*) is to describe a circle through it and through the center of each eye, as in the figure, and from the center of the farthest eye (*B*) to draw the arc *c x* from *c* to the median line. The circle is the line of equal convergence for that point, and the arc is part of the line of equal accommodation for the same.

In binocular vision, therefore, of the point *c*, convergence must occur as if for *O*, and accommodation as if for *x*, while both eyes are deviated to the right through the equal angles *O B c*, *o A c*.

The point *b* gives the base of the line which bisects the angle of convergence, and which is made by joining *b c*, while the inclination of this line to the median plane expresses the angular parallel movement of the two eyes.*

The lines of equal convergence and accommodation, if rotated round the interocular line as an axis, would describe *surfaces* of equal convergence and accommodation respectively.†

**Impulse and Work.**—This angle, therefore (*O B c*), represents the dextroducting or lævoducting work to be done in looking at any point (*c*). I do not say the *impulse*, but *work*, for effort is often disproportionate to work, owing to greater resistance or other disadvantages.

A certain evolution of nervous energy from the converging center produces a definite angular deflection inwards of both visual axes, and similarly an impulse of a lateral center produces a definite deviation of both visual axes to the right or left. The nervous impulses perform angular work, if I may so say, as far as vision is concerned and, therefore, we may assume that it is by angles that the mind judges of the work done in estimating the projection of the field of vision;

* For any point of fixation (*c*) the isogonal circle may be found by drawing from *A* and *B* straight lines at right angles to *c A*, *c B* respectively. From the point where they meet draw a straight line to *c*, the bisection of which gives the center of the required circle. Or *Euclid*, iv, 5.

† (1) To find the surface of equal convergence—the *radius* of the required circle is found by dividing half the intercentral distance by the sine of the angle. (It may be found *geometrically* by *Euclid*, iii, 33.) (2) To find the angle of convergence when an object is viewed in the median plane at a given distance from the eyes—half the interocular distance, divided by the distance of the object from the eyes, gives the sine of half the angle. Or half the interocular distance divided *into* the distance from the eyes gives the number of meter-angles.

but since the judgment is based solely upon the *impulse* put forth, any discrepancy between it and work would show itself in angular misjudgment, unless by habit the mind had come to associate a certain degree of impulse with the work it *usually* performs, instead of with the work it *should* perform compared with a smaller effort.

Such allowance is no doubt made, in whole or in part, except for unusual obliquities.

Were "impulse" and "work" exactly proportionate in the parallel motions of the eyes, all objects seen by the fovea of one eye or both, however obliquely, would be referred to the line which bisects the angle of convergence, since its inclination to the median plane would exactly express the angular impression in the mind produced by the lateral effort.

**Experiment in Impulse and Work.**—I find, however, that if a large piece of card be held very much to one side, a few inches in front and to the outer side of one eye, with a mark upon its upper border, looked at with both eyes, a finger passed up behind it generally at first misses the mark to the *outside* by nearly an inch, showing that the lateral impulse is relatively so far greater than the work it accomplishes that the mind estimates as if more angular work were done, and mentally displaces the object from the median plane by an angle greater than that of the line which bisects the angle of convergence and which only measures the work actually accomplished, not the effort put forth to accomplish it.

**Why Convergence and Accommodation are Not Inflexibly One.**—Were the relation between convergence and accommodation inflexibly complete for objects in the middle line, there would be diplopia for any object out of the middle line, except, perhaps, at one point on each side, within which diplopia would be heteronymous from relative divergence, and without which it would be homonymous from relative convergence. The nervous ties, therefore, though strong enough to relieve fusion-effort, are not so strong but what they can be overcome to meet such requirements.

**Second Reason.**—Apart from these geometrical considerations, it is found that the more the eyes look to either side, the greater becomes the practical difficulty of converging the eyes, so that the excess of converging effort required over accommodating effort increases in proportion to the amount of lateral deflection.

**Exophoria in Near Oblique Vision.**—Thus Dr. Joseph Bolton, of Nottingham, found, on experimenting with a modification of the visual camera, adapted for the purpose, the following deficiencies in convergence, with accommodation for 10 inches, his eyes being dislocated :

| For an Object 10 Inches Distant | Exophoria |
|---|---|
| On looking straight forwards . . . . . . | — 6° |
| Looking 10° to the right . . . . . . . | — 7° 10′ |
| " 20° " " . . . . . . . | — 8° 54′ |
| " 30° " " . . . . . . . | — 10° 45′ |
| " 35° " " . . . . . . . | — 12° 36′ |

The last figures show the visual axes to be actually divergent, so that if prolonged backwards they would meet at a point behind the head. It is indeed just as much as we can do to overcome this tendency to diplopia, in the lateral limits of the field of fixation, as the following simple experiment will show :

**Experiment in Peripheral Diplopia.**—Hold an ordinary lead pencil about three inches to the outer side of the right eye and, with the right eye closed, advance it just sufficiently to let it be visible to the left eye across the root of the nose. Now, open the right eye, when double images at once appear, of which the left-hand one belongs to the right eye and the right-hand one to the left eye. It will be found that it needs an appreciable effort to unite them. The fact that the images are "crossed" shows that the eyes are not sufficiently converged.

**Relative Range of Accommodation.**—Donders showed that to each fixed quantity of convergence there is attached (for the same person) a definite range of relative accommodation ; that is, there are well-defined limits within which accommodation can be made to exceed convergence or come short of it by the forced employment of concave and convex lenses.

**Relative Range of Convergence.**—For each fixed quantity of accommodation there are definite limits (in the same person) within which convergence can be lessened or increased by prisms ; lessened by prisms with their apices outwards, and increased with them inwards. Since prisms are not quite so easy to work with as lenses, this subject has not yet been so satisfactorily worked out as the relative range of accommodation. The two ranges with the same person are, of course, correlated.

**Latent Deviations (Heterophoria).**—In our experiment with the black velvet we have had occasion to notice that an eye occluded in near vision, deviates outwards under the screen. When this was observed only in its more extreme manifestations and was considered a pathological occurrence, it went by the name of "insufficiency of the internal recti," till I was able to show, in 1882, by the visual camera (Chapter XIV) it is a physiological occurrence in nearly every one, to an amount averaging nearly four degrees with accommodation for ten inches, and that as the object of vision is made to recede, it gradually lessens to practical zero in distant vision. It is not due to any fault of the internal recti, but simply to a flagging of the conjugate innervation of convergence when there is no work for it to do. Many pathological deviations occur, which are treated of in Chapter XII.

## CHAPTER VI

### Fixation, Projection and Binocular Vision

The object of ocular movements is to bring the best point of the retina to bear upon objects looked at, and thus obtain the keenest possible vision of whatever point engages the will or the attention at the moment.

When our attention is directed to any point, the eyes almost simultaneously follow, and by making them glance from point to point, so as to see a series of pictures, we gain a true conception of the shape, size, solidity and position of objects.

At other times, the eyes seem to wander of themselves, almost involuntarily, till attention is suddenly awakened by what they see.

**Point of Fixation**—The point which for the moment engages an eye is called "the point of fixation," and by a curious reversal of terms the eye is said in ophthalmological language to "fix" the object, though in reality it is the object which fixes the eye and by an involuntary cerebral mechanism imparts to it a steadiness far beyond any voluntary power to imitate.

In the dark, or with an absolutely homogeneous field before them, the eyes are always moving. We may infer this from the behavior of blind eyes, and from the fact that if even one eye be placed in the dark (Chapter XIV) it slowly, though slightly, wanders from side to side.

**Direct Vision.**—The value of the steadiness of fixation is to retain the image upon the most highly differentiated part of the retina—the "fovea centralis."

**Indirect Vision.**—Immediately outside the tiny area of acute vision the form-sense (by which we perceive the shape of objects) becomes reduced to one-tenth, the reduction proceeding still farther with greater removal.

This "indirect" vision, however, is as good, if not better, than "direct" vision for the perception of *light*, so much so that astronomers generally see a star better by looking a little to one side of it.

Moreover, in "indirect" vision the eye is remarkably sensitive to the *moving* of objects, a benificent provision to which we owe many an escape from danger.

The chief office of indirect vision, therefore, is to merely call our attention to the presence of objects, and especially moving objects, without defining their shape, in order that the eyes may turn towards them and learn their true nature by direct vision.

**Fixation-Reflex.**—Fixation is the result of a visual-reflex action of extreme intricacy, the center for which lies probably in or near the corpora quadri gemina ; we can by an effort of the will easily glance from one point to another, but when we do so, the new point becomes that which immediately fixes the eye.*

**Persistent Fixation.**—When the higher volitional centers become weakened in any way, as, for instance, in hysteria, the reflex mechanism of fixation may even gain the upper hand over volition, so that it becomes difficult to transfer fixation from one point to another. Dr. Gowers, for instance, says : "I recorded, some years ago ("Brain," vol. ii), a case in which the reflex fixation of the eyes was brought into salience by disease. If the patient, looking at one object, was told to look at another at some lateral distance from the first, his head was instantly turned in the direction of the second object, but the eyes remained fixed on the first by a movement as rapid as that of the head, but in the opposite direction, and then they were slowly moved into the position corresponding to the second object. The patient was in the last stage of progressive muscular atrophy."†

I was interested to note in the record of a case of poisoning by a certain plant, the *Cicuta virosa*, the following symptoms : "She stares with unaltered look at one and the same place, and cannot help it." It may be, however, that the symptom was not due to any specific action of the plant, but to hysteria set in activity by the poison.

It is not unlikely that one form of "fascination" depends on this loss of voluntary control over fixation, though probably it is oftener a more purely psychical phenomenon. It is, to use a simple illustration, as though a boy stands before a rock with a limpet in his hand : he can choose any spot he pleases to place the limpet on, but now he finds that to transfer it to another spot is not so easy.

**Lower Animals.**—The foveal differentiations of human eyes have to be much more perfect than those lower in the scale of

*Though in ordinary vision the "point of attention" (which engages the mind) becomes instantaneously the "point of fixation" (which engages the eye) ; or *vice versa*, a distinction must be observed between the two, since we can, by an effort of the will, fix one point while directing our attention to a neighboring one. We count, indeed, on the possession of this faculty in our patients when we test their field for colors, or their indirect vision by the perimeter.

† "Diseases of the Nervous System," vol. ii, p. 195.

creation, and it is probable that in most animals the whole retina possesses properties intermediate between the center and periphery of our own, so that their sense of the form of objects is inferior to that which direct vision, and superior to that which indirect vision affords to ourselves.

**Central Fixation.**—The point of fixation is surrounded by an area of acute vision said to be about three-fourths inch in diameter at the distance of a foot (Le Conte). For small objects, therefore, it may suffice to fix one point, since all the other points will lie in this area; but for larger objects it is essential to glance from point to point.

"The anatomical fovea has a breadth of 0.2 mm. to 0.4 mm. (*Henlé*), or, viewed from the posterior nodal point (which is 16 mm. from the retina) an angular breadth of 45′ to 1° 30′. On looking at the sky the fovea would, therefore, cover a portion having two or three times the diameter of the moon, which corresponds to half a degree. The point of fixation has a much smaller breadth, for we can easily tell whether we are fixing the right-hand or left-hand margin of the moon. In general, as soon as we can distinguish that two points are discrete we can tell which we are fixing. It was *Javal* who emphasized this fact" (Tscherning).*

By "central fixation" we mean fixation exerted to bring the images of objects on the point of acutest vision, and this is almost the only kind of fixation which exists in the ordinary use of healthy eyes; but since it exists in the interests of direct vision, it becomes lost as soon as the power of direct vision is destroyed: as, for instance, by disease of the macula, or a central scotoma. The eye then tends to wander, since the central blind area of the retina is surrounded by a zone in which no point of acuter vision than the rest exists, or, if it does exist, the eye has yet to learn to use it exclusively for fixation. If central vision is impaired at birth, or shortly afterwards, true fixation is not often acquired, and nystagmus frequently results. Ophthalmoscopic corneal images, as Priestley Smith has pointed out, afford a simple means of observing whether an eye has central fixation or not.

**"Fixation-Line."**—Having defined the "point of fixation" as that point outside the eye which at any moment engages the eye, it is easy to conceive the "axis of fixation" or "fixation-line" as an imaginary straight line extending from this point to the center of motion of the eyeball.

* "Physiologic Optics," p. 36.

**Field of Fixation.**—The field of fixation is the expression of the mobility of the eye in all directions. It is, for this reason, sometimes called the "motor field."

If we think of the eye as placed in the center of an imaginary sphere, the part of the sphere which bounds the extreme sweeps of the fixation line is the field of fixation.

Fig. 37 gives Landolt's measures for the greatest possible excursions of an eye in all directions, while Fig. 38 gives Schuurman's. Both of these observers distinguished between the lateral mobility of hypermetropic, myopic and emmetropic eyes. In both

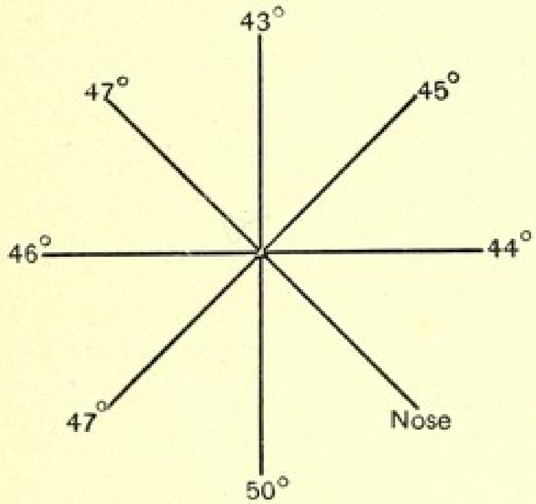


**Fig 37**

Landolt's Figures for the Field of Fixation.

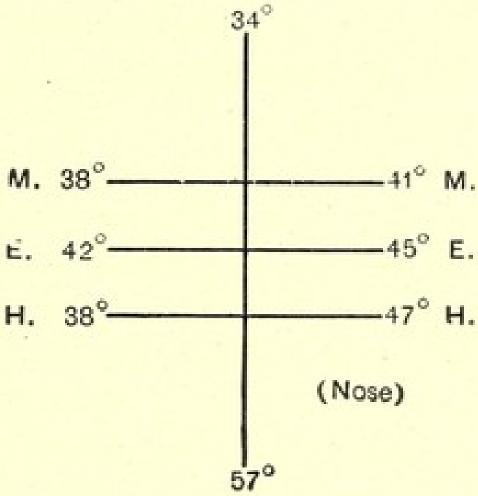


**Fig. 38**

Schuurman's Figures for the Field of Fixation in Myopia, Emmetropia and Hypermetropia.

figures the upward mobility of the eye is considerably less than the downward. Stevens gives 33° for the maximum elevation and 50° the maximum depression of normal eyes.*

**Binocular Fixation.**—It is frequently taken for granted that binocular fixation and stereoscopic vision are necessarily the same thing, but the latter requires a higher order of cerebration than the former

On throwing the light from the ophthalmoscope into the eyes of a patient after operating for squint, it is not uncommon to find that while both eyes apparently fix the mirror quite truly, yet the subject of the experiment suppresses the image of one eye. It is, of course, very difficult to prove that binocular fixation under these

*To departures from this proportion Stevens has given the names of "anœphoria" or "kataphoria," according as elevation exceeds or falls short of its proportion to depression.

circumstances is *real* instead of apparent, but it is well to bear in mind the possibility of its existence.

**Projection.**—Objects whose pictures are formed upon the retina are not themselves supposed to be within the eyeball, but are mentally relegated to some external position in space. This cerebral process is called "projection." The more perfectly it is performed the more truly the projected pictures of objects coincide with the objects themselves. Though projection is a congenital faculty, since there never was a time when we imagined objects to be located within our eyes, it is perfected during the exercises of childhood when the real position of objects is constantly being discovered by other senses.

Given the direction of an object from an eye, and its distance in that direction, its position is known. It is convenient, however, to treat the "perception of distance" as a separate study, and treat projection as if related only to "direction."

It is important to recognize that projection is not a faculty of the *retina*, but is a *mental act.*

**Field of Projection.**—Related by its own constant angle to the "line of direction" in which a picture focused on a single fovea is projected, there is a definite and unchangeable line of direction belonging to every percipient element in the retina.

Though the attention of the mind is generally concentrated upon whatever picture occupies for the moment the fovea, the whole retina is covered by a continuous sheet of pictures of other objects, both near and distant, some in and some out of focus. It is the projected images of these which constitute the field of projection.

Since pictures on the retina are inverted and since the direction of projection coincides practically with the axes of the incident pencils of light which enter the pupil from outside objects and which, therefore, cross each other in the crystalline lens, it follows that the field of projection is re-inverted, so that its right half corresponds to the left half of the retina and its upper half to the lower half of the retina. For this reason objects, in spite of their retinal images being inverted, appear erect and as they are.

**Malprojection of a Field.**—In natural acts of vision the direction of projection of an image on the fovea coincides with the visual axis of the eye; but when, under some unusual or pathological conditions, the direction of foveal projection is displaced away from the visual axis, every part of the field of projection is equally displaced in the same direction, so as faithfully to retain its relation to the foveal projection. In other words, projection *in* a field is always true,* though projection *of* a field may be "false."

**Coincidence of the Two Foveal Projections.**—Pictures formed upon the two foveæ are projected under all conditions very faithfully to the same spot in space.

Thus, in recent paralytic squint, two candles held in line with the two visual axes invariably appear as one.

Again, if a piece of paper be pricked through with a pin at two points separated by the interocular distance, and be held up close to the eyes so that distant objects can be seen through them, the two holes themselves are seen as one, in the median line.

Another well-known experiment is to create a tiny foveal after-image by looking at a bright point of light with one eye; then, whatever object be fixed by the other eye and however much the spectralized eye may be artificially displaced even by forceps, or made to squint, the after-image still clings tenaciously to whatever point is fixed by the other eye.

**Corresponding Points.**—What is true of the fovea is also true, in a less-pronounced way, of all other parts of the retina. Every percipient element in one retina has a corresponding element in the other (situated similarly with respect to its fovea, *i. e.*, at an equal distance in the same direction from it, so that its projection in space is identical).

**Double Set of Corresponding Points.**—In very old-standing squint (strabismus incongruus) it sometimes happens that certain, at least, of the percipient points in one retina have two corresponding points in the other, of which one was originally true, and is, therefore, again true when the eyes are put straight by operation, and the other created during the condition of squint.

**Rotation of the Field of Projection.**—It has seemed to me possible that without any actual translation of the field as just described, the corresponding points may become altered in some cases by rotation as a whole about the point of fixation. In a case, for example, of complete traumatic paralysis of the superior oblique I found, years after, that the field of projection was still perfectly untorted on looking straight forward. Since the eye gave much evidence otherwise of so-called secondary contracture (consecutive

*This statement, of course, supposes absence of anatomical changes in the lens, etc.

deviation), it can scarcely be conceived that in this case there has been no actual paralytic torsion.

**Physiological Diplopia.**—In every ordinary act of vision a vast number of objects do not throw their images on corresponding points of the two retinæ. For every position of the point of fixation there is what is called a "horopteric surface," all objects in which are seen single, while all other objects would be seen double were they closely analyzed.

If the two forefingers be held before the face in the median plane, one in advance of the other, and the farthest one be fixed, the near one is seen double; and by momentarily closing the right eye it is easy to assure one's self that the left of the two images belongs to the right eye and the right image to the left eye. This *proximal diplopia* (as we may call it) is, therefore, *crossed.* (See Fig. 40.)

If, on the other hand, the near finger be fixed, of the two images of the distant one which now appear, the right one disappears on closing the right eye, and the left on closing the left, showing that the *distal diplopia* (as we may call it) is *homonymous.* By such experiments, we learn that all objects nearer to us than the point of fixation (and the horopteric surface connected with it) have crossed images, while all objects beyond have homonymous ones. Our higher intellectual powers are insufficient to inform us whether any double images which we see are crossed or homonymous, proximal or distal; but some inferior center seems to have no such difficulty, for as soon as an effort is made to unite the images, it always commences in the right direction without any preliminary trial to discover whether it is an effort of convergence or one of divergence that is called for.

**Suppression of Images.**—In the physiological diplopia of people who are right-handed, the image which belongs to the right eye is apt to appear more substantial-looking than the other (Tscherning), and this is probably especially the case with those who are accustomed to frequently use the right eye separately, as, *e. g.*, in aiming. Consistently with this indication, while attention is diverted from the diplopia and concentrated upon the point of fixation, the less substantial image of objects out of the horopter is in most persons so entirely ignored by the mind as to be what is called "suppressed." Even when it is not so, the diplopia attracts no attention, because from absence of critical analysis it is undistinguished by the mind from that other kind of indistinctness which is due to the object being out of focus.

**Origin of Projection.**—In projecting the retinal field into space the mind must have some "point of origin" for the radius vector, or "line of direction" in which the projection is made. Hering places this origin midway between the two eyes, as if they were united into one cyclopic eye. His idea is supported by the double pin-hole test previously mentioned, and is no doubt true of those whose eyes are of equal value in binocular vision. Some, however, and possibly the majority even of those who have equal visual acuity in the two eyes, seem to use one eye rather as the *aide-de-camp* of the other, than as an equal partner in projection. One is then called the "directing eye" (Javal), since the origin of projection appears to be displaced to coincide with this eye. Tscherning finds this condition in his own case and that of several others, and himself evidently judges of the position of objects much more truly with his right eye than with the left, probably because it has been most often used separately.

**Test for True Projection.**—The following modification of a very old test by Hering enables the co-ordination of hand and eye to be well tested : Take a large piece of cardboard, marked in the middle of each surface with a short vertical line, these lines being exactly counterposed, which can easily be ensured by pricking the cardboard through at their extremities. Holding the card vertically six inches before the patient's eyes, let him endeavor, by passing his hand behind the cardboard, to place his finger exactly behind the vertical line which he sees. He should make the attempt as carefully and judgingly as possible, with first one eye shut and then the other, using also in each case first the right hand and then the left. The surgeon standing behind the cardboard can see perfectly from the line on the back the nature of any failure in projection, while the patient never himself learns in what direction his aim has been missed. Herein lies the advantage of modification, for if once the patient knows his error, he makes mental allowance for it in his next attempt.

**Illustrative Errors of Projection.**—In near vision, as we may see elsewhere, an excluded eye generally deviates outwards, and hence arises an error in monocular projection. Fig. 39 illustrates, as an example, the case of an aurist examining the drum of an ear. The left eye, having nothing to do, diverges, and the apparent position of the drum, as represented in dotted outline, lies in consequence midway between the visual lines.

Another error of projection may be demonstrated by quickly thrusting the finger at a pencil held about a foot away from the eyes at the extreme lateral limit of the motor field while the eyes are strongly turned toward it. The finger will generally miss its mark to the outer side of the pencil. The reason of this error is that the ordinary calculations of the mind are formed from the more habitual smaller obliques of vision, and the excessive effort required to produce unusual obliquity of the visual axes creates the impression of a proportionately displaced object. At the limits of the motor field, strong increments of effort produce smaller increments of result, owing to mechanical difficulties in the motions of the eyes.

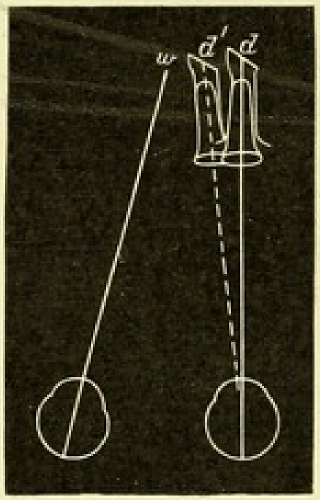


**Fig. 39**

**Mis-projection by an aurist who closes, or does not use, his left eye.**

Malprojection, kindred to the last, is seen to a more marked extent when a muscle is paralyzed. Since the mind is counting on every muscle to do its duty, the least failure in contractile response to stimulus results in malprojection proportionate to the failure, and in the direction which is suggested by the greater effort put forth.

**Fusion.**—Since corresponding points have their pictures projected to the same point in space, the mind cannot but regard them as one, since it cannot conceive two objects occupying the same place at the same time.

But there is to be considered more than the mere existence of single vision : there is a natural love of single vision, expressed by a strong sub-conscious desire to bring together and thus fuse any double images of the same object while even one of them engages the attention of the mind. Withdrawal of attention to another object almost, if not quite, abolishes this desire ; also anything which makes one image differ from another, either in color, size or shape.

It is the absence of this "abhorrence of double images" or "love of single vision," as it has been called, in very long-standing cases of strabismus which is the chief difficulty encountered in training the eyes to work again together. When entirely absent, it is said that there may be even a desire to separate the images in order to see one of them more clearly, a condition described by Graefe as antipathy to single vision. But this antipathy is, I fancy, merely a mental choice, not a sub-conscious contrast to the "love." It is quite reasonable to expect it, since one field embarrasses the other less in proportion to its displacement therefrom.

**The Power of Overcoming Prisms.**—If a prism be held before one eye, its effect will be to displace the image belonging to that eye to another part of the retina, so that, for a moment, vision will be double. The image seen by the naked eye is the "true" image, since it is mentally referred to its true position in space: the image seen through the prism appears displaced from the true position of the object in the direction of the apex of the prism by an angular departure equal to the angle by which the prism deviates light, and which for brevity we call the "deviating angle of the prism." If the prism be weak enough, the co-ordinating centers endeavor to overcome the diplopia by directing the embarrassed eye towards the apex of the prism, so as to again receive its image on the fovea. This is done by the conspiracy of at least two conjugate innervations, and when it is effected, vision is again single.*

**Apparent Prismatic Displacement.**—Now, however, the object does not appear to occupy the position either of the former true one or of the former false one, but lies exactly *midway* between the two. A person with both eyes open and a prism before one eye, will, as I have shown elsewhere, misjudge the position of objects, even though he see them single; but his malprojection will only equal *half* the deviating angle of the prism. If he cover the naked eye with his hand, under these circumstances, the image may appear to move slowly till the malprojection is doubled. All this proves that the innervations at play are conjugate, according to the principles already mentioned.

When distant objects are viewed, a prism higher than No. 8 (with 4° deviation therefore; for the deviation of light by a prism is by an angle about half its apical angle), with apex *out*, cannot generally be overcome.

Since the prism is held before one eye, we have to mentally divide its effect between the two eyes. It follows, therefore, that a

*For diagrams to illustrate this, vide "Ophthalmological Prisms" (J. Wright & Co.), pp. 62, 63.

divergence of 2° from parallelism, of each eye, is the greatest divergence which even the love of single vision can usually induce the co-ordinating centers to effect. It is far otherwise, however, with prisms whose apices are placed inwards, and which can be increased to much greater strengths without inducing diplopia. Since, in the vertical motions of the eyes, there is nothing known corresponding to the converging innervation, it is remarkable that prisms with their apices upwards or downwards can be overcome at all. As a matter of fact, to be overcome, they must be very weak. A prism of from 2° to 4° (1° d. to 2° d.) before one eye, is the strongest vertical prism that can generally be overcome, without practice.

**Breadth of Fusion Power.**—When diplopia is created artificially, as by prisms, the smaller it is, *i. e.*, the less the double images are separated, the greater is the desire, and the easier is the task, to effect fusion. There are limits to the separation of the images, beyond which the diplopia becomes insuperable. These limits define the "breadth of fusion" (as it is generally called for brevity).

**Three Conditions.**—When the breadth of diplopia is (1) *greater* than the breadth of fusion power, no effort can unite the images. When they are (2) almost *equal*, the images may be united by a great effort for a short time. When the breadth of diplopia is considerably (3) *less* than the breadth of fusion power, the images are easily united. These three conditions are found respectively in "permanent squint," in "periodic squint" and in "latent squint" (heterophoria). The difference between them is merely a question of degree.

There is a great difference between the breadth of fusion power in different individuals, and it varies also for different distances of the object-point, and according as the diplopia is homonymous or crossed; according, too, as the health and the will-power vary.

The power to fuse horizontally separate images is much greater than the power to fuse those which are separated vertically; and "crossed" diplopia is more easily overcome than "homonymous," since converging effort is easy and diverging effort difficult.

The best way to estimate the breadth of fusion is to find the strongest prisms which the eyes can overcome: the strongest prism base in added to the strongest prism base out, gives the *horizontal* *breadth*, while the strongest prism base down added to the strongest prism base up, gives the *vertical breadth*.

A convenient convention to adopt is that prisms base in measure the *negative breadth* of fusion, and that prisms base out measure the *positive breadth:* the two together, of course, constitute the *total amplitude*.

In making tests of this kind with prisms it is necessary to remember that anything which makes one image differ from the other lessens the desire to unite them ; hence, in using strong prisms which alter the image by chromatic and prismatic aberration, it is best to divide them equally between the two eyes, so that the two images shall be equally perturbed.

**Caution.**—In cases of defective converging power at reading distance some have tenotomized the external rectus with the result of producing homonymous diplopia in distant vision. Such mistakes would have been avoided by taking the trouble to test how much negative breadth of fusion the patients possessed (or, in other words, how strong a prism, base in, they could overcome) in distant vision. A defective negative breadth is an evident contra-indication against division of the external rectus tendon, for homonymous diplopia in distant vision is the most difficult of all the horizontal forms of diplopia to overcome.

**Binocular Fixation.**—We should, perhaps, draw a distinction between (*a*) Binocular fixation, (*b*) Binocular vision and (*c*) Stereoscopic vision or perception of relief. The first of these is beneath the region of consciousness, the two eyes jointly fixing the same object from habit, even when the mind suppresses or at least pays no regard to the vision of one eye. I have seen cases in which it seemed that *binocular fixation* was preserved, both visual axes being directed correctly, so far as objective tests could discover, even though diplopia could not be elicited by prisms. However that may be (for it is confessedly difficult to understand), there is no doubt that the second should be distinguished from the third, for *binocular vision*, in which certain objects seen by one eye are mentally recognized simultaneously with vision by the other eye, is inferior to the power of erecting bodies into "relief" with such an instrument as the stereoscope. Some have this last power much more intensely than others.

**Monocular Perception of Distance.**—It is well to know in how many ways a *single eye* can gain an idea of the third dimension, so as not to be deceived when testing for true binocular vision. They are :

(*a*) *Aërial perspective.*—More distant objects are veiled by a greater depth of atmosphere, and the greater the depth of atmosphere the bluer also this veil is. In mountainous districts, when the atmosphere is unusually clear, distances are judged to be less than they really are ; the reverse being the case in a fog.

(*b*) *Shadows and overlappings.*—With the source of light behind us, an object which throws its shadow on another object is, of course, nearer. So also is an object which hides part of another object.

(*c*) *Visual angle of known objects.*—The size of many objects is so well known, that their distance can be estimated by their apparent magnitude, as, for instance, in the case of men, horses, etc.

(*d*) *Mathematical perspective.*—The gradual decrease in the size of similar objects and the gradual approximation of parallel lines, is too well known to need further description here. The number of intervening objects also influences our judgment ; hence, distances at sea appear less than on land, it is stated.

(*e*) *Focal indistinctness.*—The farther objects lie from the point of distinct vision, on the far or near side, the more hazy they are.

(*f*) *Accommodation.*—It is only in judging of comparatively near objects that any assistance is derived from the conscious effort of accommodation. As a rule, a greater effort of accommodation makes us think objects to be smaller.

(*g*) *Parallax.*—For objects which are not too distant, this is by far the most important and valuable indication to a single-eyed person. Though he cannot see the object, as others can, from two points of view simultaneously, he can do so consecutively, by moving his head from one position into another. He sees, therefore, as we should, if first one eye were active and then the other. Such movements of the head have to be guarded against in some of the clinical tests for binocular vision.

**Binocular Perception of Distance.**—Here, in addition to the criteria just enumerated, *convergence* comes into play, as well as the fact that the nearer an object is, the more dissimilar are its two pictures upon the two retinæ, thus altering the character of the physiological diplopia. The absolute amount of convergence exerted is not a great help, but to any volitional increase or decrease of it the mind is very sensitive. The nearer an object, the greater, of course, the convergence it requires, and by converging *from* one object *to* another we learn their relative distances.

**Stereoscopic Vision or Perception of Relief.**—It has been said by Dove and others that objects appear solid when seen by so instantaneous an illumination as that of an electric spark. If this be so, the appearance of solidity must be due to the physiological diplopia of those parts which are not seen single. For the analysis, however, of "relief" and the quantitative perception of depth, it is necessary that the eyes should unite in succession different parts of the object by consecutive increase and decrease of convergence (Brücke). Hence, many find that with a stereoscope the appearance of relief does not appear until after a few such motions have been made. Fig. 40 shows how this principle works in the case of a lead pencil, held pointing forwards in the median plane a little lower than the eyes. When the far end of the pencil is fixed, the near end is seen double. By converging a little more so as to fix the middle of the pencil, both ends exhibit diplopia of half the magnitude which the near end at first exhibited, and by converging still more to look at the near end the far end exhibits wide diplopia.

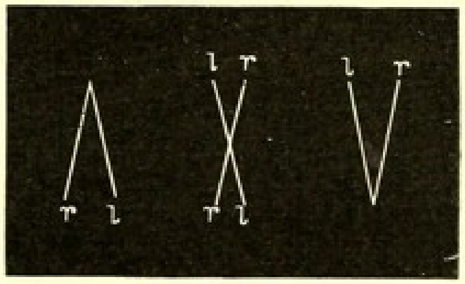


**Fig. 40**

To show that Proximal Diplopia is crossed, and Distal Diplopia homonymous.

**Stereoscope.**—Fig. 41 gives the plan of a Brewster's stereoscope, *A* and *B* being the pictures. These are taken from slightly different points of view with a photographic camera, so that the distance between identical objects in the foreground of the two pictures is less than between identical objects in the background. To fuse the former, therefore, more convergence is called for than to fuse the latter. Foreground objects and background objects cannot both be fused simultaneously : if they could the

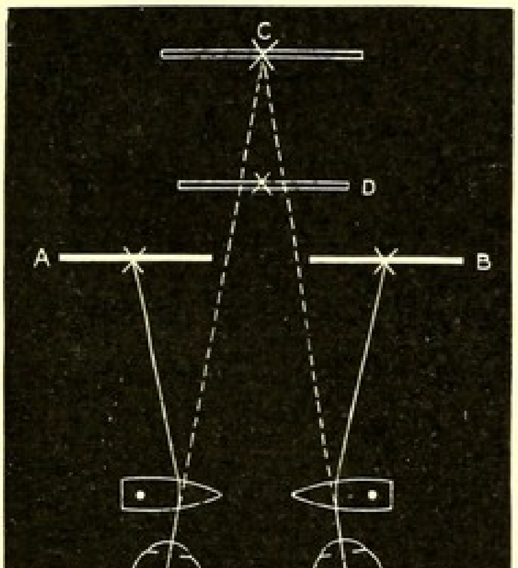


**Fig. 41**

Plan of an ordinary Stereoscope (the pictures, however, being separated more than usual for diagrammatic purposes).

sensation of relief would disappear. While looking at the foreground of the scene depicted, there is physiological diplopia of the background, and *vice versa*, just as with the lead pencil of Fig. 40. The decentering outwards of the lenses enables the eyes to converge somewhat, as, for instance, to *C*; but the united picture is generally only projected to *D*, since the knowledge of the convergence, which acting alone would project it to *C*, is in part overborne by the conscious knowledge of the size of the stereoscope which tends to bring the projection towards the plane of *A B*, unless the picture itself is one of a scene we are accustomed to think of as distant. In that case the projection depends a good deal on the powers of imagination which make the stereoscope forgotten. The pictures (*A*, *B*) generally lie slightly within the focal length of the lenses, so that accommodation is not wholly relaxed, and there is nearly always a certain amount of associated convergence. The distance between the pictures is generally made greater than the inter-ocular distance, to allow room for larger pictures to be used. A handy form of cheap stereoscope is shown in Fig. 42. Of the expensive ones, probably the best for clinical purposes is Javal's "Stéréoscope á cinq mouvements."

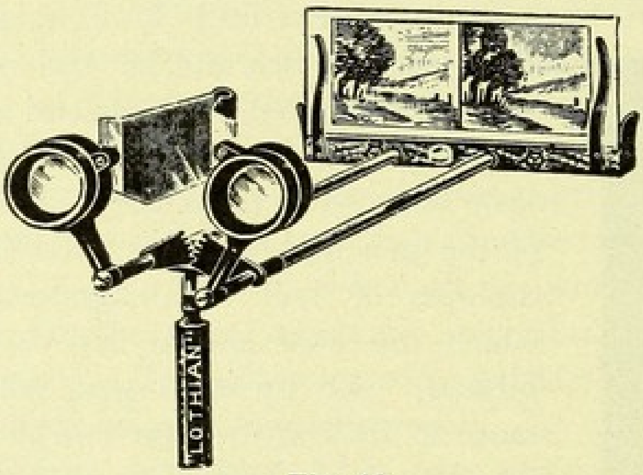

**Fig. 42**

So various are the experiments which can be made with a stereoscope that the interested reader is referred to some book which, like Javal's, is wholly devoted to the subject. One of the best devices is that by Green, in which the letter L is placed before one eye and a letter F before the other. The patient who uses both eyes simultaneously sees them combined into an E. This is a test for binocular vision, but not for stereoscopic vision. No stereoscopic test for the notion of relief is quite so clinically satisfactory as Hering's drop test, for in most others we have to rely upon the patient's statements, without being able to verify them in the same unmistakable way.

**Mr. Berry's Sterescope.**—This is a very ingenious and satisfactory arrangement. Before each eye, in a stereoscope is placed a fixed circle, with a small movable circle within it, as shown in Fig. 43. By a simple mechanism the two small circles can be made to mutually approach one another, as shown by the small continuous circles, or mutually recede from one another to occupy the position shown by the small dotted circles. When their separation from each other is at its least, they resemble the images in the foreground of a landscape, so that the device is seen in relief, like a truncated cone or a bucket upside down. But when their separation increases, so as to be greater than the separation of the large circles, they resemble images in the background of a landscape and produce the appearance of a hollow cone or empty bucket. During the motion from one position to the other the stereoscopic effect is one of movement in the third dimension, the small circle appearing to sink from a plane above the great one to one which lies beneath it. This apparent movement, says Mr. Berry, is so evident, especially if the experiment be made in semi-darkness, that young children can at once say whether they see it or not, and seeing it, of course, implies the exercise of stereoscopic vision.

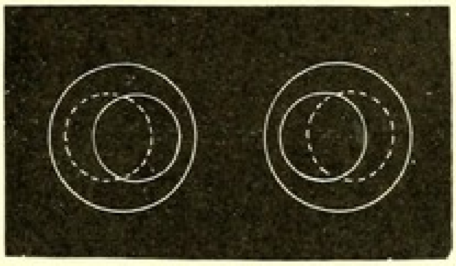

**Fig. 43**
Mr. Berry's Sterescope.

**Lecture Contrôllée.**—Javal's long-known plan of holding a pencil vertically midway between the patient's eyes and a page of print to see whether he can read continuously without suddenly bobbing his head to avoid the pencil, is a test not of stereoscopic vision nor even exactly of single binocular vision, but of the power of rapid alternate binocular vision.

(*a*) If one eye be amblyopic he cannot, of course, read that part of the print which lies behind the pencil, as viewed from the good eye, without bobbing his head.

(*b*) If both eyes have sufficient visual acuity and yet are not working together, there must either be a head-bobbing or else a pause from disconcertment when the deviated eye has to suddenly take up fixation, followed immediately by a second pause before the sound eye can resume it. An excellent arrangement by George Bull enables the patient to place against his forehead a light framework which supports both the print and a vertical rod in front of it. Previous to this he employed a bent strip of brass to be held against the book by a wooden spring-forceps. A somewhat similar arrangement, but to be held by the thumb only, has been used by Priestley Smith. What I use myself is a Holmes stereoscope with two crosspieces, one for holding the print, the other for holding a series of upright strips of metal or whalebone, the strips being made of a dull black. Javal, too, has constructed a "multiple controller" consisting of five bars side by side.

**Hering's Drop Test.**—In this test the patient sees an object for so brief an interval that there is scarcely time for a full movement of convergence to occur. It tests, therefore, rather what has been called the "notion" of relief, than the "measurement" of it. It requires a flattened cylinder or shallow rectangular wooden box about ten inches long by three or four broad, and open at both ends. From the farther end two wires project forwards and outwards, connected at their extremities by a horizontal thread which is provided with a small bead at its mid-point for the patient to look at through the cylinder. Fig. 44 shows a very satisfactory home-made arrangement consisting of two cylinders of cardboard fixed together, the only disadvantage of which is that the two circular extremities are apt to solicit their own fusion and thus interfere with the free movements of convergence. Whatever form is used, it is important to exclude all vision of the operator's hands. Small objects, such as beans or marbles, of different sizes, are dropped from one hand into the other, some beyond the thread and others within it, taking care that on the whole those which fall beyond the thread are a little larger than those which fall within it. If stereoscopic vision exist, he will almost always give a correct answer to the question on which side of the string the ball falls ; but if not, nearly half the answers will be wrong.

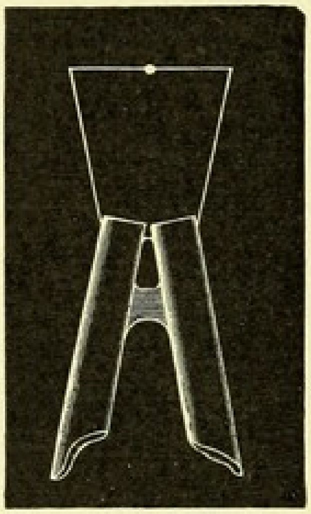

**Fig. 44**
Home-made form of Hering's Drop Test.

## CHAPTER VII

### Strabismus

**Definition.**—Strabismus may be briefly defined* as "inconcert of the fixation lines," or as "a defection of one fixation line from the other. It exists whenever the two visual axes are not directed simultaneously to the point of fixation. Only one fixation line deviates as a rule, and the angle of its defection measures the squint.

**Chief Division.**—The chief division of true squints is into *paralytic* and *non-paralytic.* This division is almost identical with that into *incomitant* and *comitant* squints, since in nearly all paralytic squints the conjugate movements of the eyes are incomitant, *i. e.*, are unequal in certain directions of vision, as evidenced by increasing separation of the double images; while, on the other hand, in nearly all non-paralytic squints their equality is so preserved that the squint remains of the same magnitude in whatever direction the eyes look, provided accommodation remains unchanged. We shall see, too, further on, that in paralytic squints the "secondary" deviation, *i. e.*, that of the better eye when it is placed behind a screen so as to oblige the squinting eye to take up fixation, is greater than the primary, while in non-paralytic squints they are equal. (Paralytic squints are treated in the next chapter.)

**Horizontal or Vertical.**—When an eye squints in or out, the squint is horizontal and is called "strabismus convergens," or "divergens," as the case may be. When an eye squints up or down, the case is one of vertical squint and may be "s. sursumvergens" or "s. deorsumvergens,"† according as the squinting eye is higher or lower than its fellow. Horizontal and vertical elements very frequently co-exist, and it is rare to find a pronounced old convergent squint that has not a slight vertical element as well.

**Alternating or Unilateral.**—In the first, alternating squint, the patient fixes with either eye at pleasure, the other squinting while

*It will be seen that I have not felt able to adopt one author's suggestion to make defect of the fusion faculty a necessary part of the definition of squint. To do so would make the definition far too narrow and leave unprovided for several varieties of squint due to quite other causes.

†I prefer the more manageable terms, "s. ascendens" and "s. descendens," but have retained those in the text in deference to usage.

he does so, for the reason that the two eyes are of such equal value that he has no preference.

Worth finds that fifteen per cent. of constant squints belong to the alternating variety and divides them into "accidentally alternating squints" and "essentially alternating squints." The first class only differs from monolateral squints in the accident of the eyes being of equal refraction. The second class has a congenital total inability to acquire fusion. Since there is no "anopsia" in alternating squints, there is, of course, no "amblyopia ex anopsia." Alternating squints of the "essential" class are, of course, only capable of cosmetic correction.

A large number of squints are transitions between the completely alternating and the completely monolateral varieties, one eye squinting very much more than the other, but not exclusively. Needless to say, even the occasional use of the generally squinting eye greatly retards the development of its amblyopia, though there is little doubt that the longer such a squint is neglected the more it tends to become completely monolateral.

In contrast to squints of this kind, in which either eye takes up fixation indifferently, most squints are "*unilateral*," the patient having a distinct preference for one as the "working" eye. The way to distinguish to which of these classes a squint belongs, is to screen the working eye; this makes the other take up fixation. If, on unscreening, the transference continues unchanged, the squint is alternating; if, however, the squint reverts to its original eye, it is unilateral. In *unilateral* squints the squinting eye is nearly always determined by some diminution of visual acuity, either retinal or from higher ametropia, astigmatism or corneal nebulæ, conditions which always predispose to the development of squint. Traumatic cataract and macular hemorrhage are mentioned by Percival.

**Strabismus Convergens Concomitans.**—The great majority of convergent squints are of this kind, being purely due to excessive activity of the converging innervation.

Nearly all cases of concomitant convergent squint disappear under chloroform, showing that the internal recti are not contractured or structurally altered, but only unduly innervated.* In most cases this activity was at first occasioned simply by association with excessive accommodative effort called forth either by hypermetropia

*I have seen one case, but only one, in which the eyes (previously divergent) converged under chloroform.

or possibly, in a few cases, by paresis of the ciliary muscle, as suggested by Javal. Convergent concomitant squint is sometimes congenital, but far more frequently commences about the age of three years, when children first begin to regard small objects attentively. Possibly at this age accommodation begins to require a greater effort than before, from changes in the consistency of the lenses or a diminution of its early rotundity. Or, it may be, that sometimes at the age when a squint begins, the insulation between accommodation and convergence is still more incomplete than usual, so that strong accommodation is impossible without equally strong associated convergence from overflow of nervous force. The frequent association of squint with some other defects of the nervous system has been pointed out in France.

It has always been a difficult question why some hypermetropes squint and many others of similar refraction do not. Later development than usual of the insulation just spoken of is an extremely probable cause, while congenital deficiency or late development of the love of single vision or feeble intensity of the fusion faculty is another possible cause, of which we must take an equal account. The success obtained by Worth in training the fusion faculty in very young squinters shows how rarely the faculty is completely absent. It proves, therefore, that other causes must co-exist in the great majority of cases, since it would be extremely unlikely that after using the fusion faculty for three years it would be surrendered at the usual age when squint comes on, unless its surrender were compensated for by some other gain. It is evident that any squint due *solely* to defect of the fusion faculty would date from infancy. When once formed, a squint persists from innervational habit.

The influence of *habit* is seen in the fact that accommodative squints are generally not lessened by as many meter angles as there are diopters of refracting power in the correcting lenses (Berry). This is proved by measuring the squint first with, and then without, correction.

Since the innervation is common to the two eyes, it affects them both equally, and only the desire for fixation keeps them both from squinting. When one eye looks straight forwards, in order to fix an object, doing so doubles the squint in the other eye, so that one eye bears the blame for the squint in both.

A squint is often increased temporarily by nervous excitement—a fact which also points to its innervational character. This nervous element must be distinguished from the accommodative element. In some cases *emotion* seems to excite certain oculomotor centers more than others, so that a squint is temporarily increased under its influence. This increase is not necessarily an increase of convergence only, but if there be already a vertical element in the squint, that too may increase under the influence of emotion. The surgeon's measurements, therefore, may lead him to form an exaggerated opinion of the squint, since it becomes greater during consultation. Happily these cases, in their marked forms, are rather on the rare side. They should be approached with great caution, if the question of operation has to be considered. It is well known too how frequently such reflex irritation as helminthiasis accounts entirely for a temporary squint, and I have proved that even slight irritation of the *primæ viæ* from indigestion may stimulate the converging center enough to cause a temporary latent squint. Another cause of temporary squint is hysteria ; cases of this kind are, however, more frequently classified under the name "spasm of convergence."

**Accommodative Squint.**—This name is given to a squint which disappears during a vacant stare, appears when attention is fixed and increases markedly as an object of fixation is made to approach the eye. In its incipiency every accommodative squint was at first only occasional, occurring during close vision of near objects, and therefore (Javal) likely to be unnoticed, owing to the inclined position of the head. The child, finding that by allowing the squint to occur, he can see distinctly with less effort, forms the habit of squinting more and more. Accommodation is effected more easily when supported by a full, or more than full, share of associated convergence. Once formed, the habit of thus assisting the accommodation cannot be broken, a new relation is formed between the two efforts, and the squint becomes less and less confined to near vision. At this stage, even though in distant vision squint should never actually occur, the tendency to it is evidenced by the way in which an eye deviates inwards as soon as it is screened by Javal's disk of ground glass, or in any other way "dissociated" from its fellow (Chapter XII). There is, therefore, at this stage, "*latent*" or "*superable*" squint in distant vision, combined with "*insuperable*" squint in near vision. At a later stage the squint becomes, even in distant vision, insuperable, and thus what is called a "*permanent element*" is by degrees developed in addition to the "*variable element*," which is added to it whenever accommodation is active.

**Treatment of Accommodative Squint.**—The treatment of accommodative squint lies evidently in the correction of refraction. Less accommodation is then called for and, therefore, less associated convergence. The cure takes place completely and at once if the squint be in its early periodic stage ; but since at the time when we first see a squint the hypermetropia has generally become much less than when the squint began, owing to the development of the eye, the diminution of accommodation by the spectacles is much less than the excess of accommodation which originally brought about the habit. The correction of refraction does not always cure even an accommodative squint at once, but lessens it by degrees. Occlusion of the fixing eye for a considerable time, to improve the working powers and the visual acuity of the habitually-squinting one, is a good adjunct.

Another treatment for accommodative squint is the instillation of pilocarpine drops, which make the ciliary muscle respond more readily to impulses, thus lessening the effort of accommodation and with it the "associated convergence," but it seems to me to be only palliative.

**Convergent Squint Without Hypermetropia.**—A fair proportion of convergent squints are found to exist without hypermetropia or hypermetropic astigmatism. Some of these may possibly, though not very probably, be due, as Buffon believed, to imperfect visual acuity of one eye leading to voluntary squinting in order to get rid of the disturbing effect of a blurred image. A far likelier history in many cases is that hypermetropia existed at an early age, which has since disappeared. In others the want of balance seems inherent in the musculature, while yet others may have had at an earlier date some paresis either of the ciliary muscles or, and this is far more common, of one or both of the external recti at birth. In another important class the patient squints because there is congenital deficiency of the fusion faculty, just as there is deficiency of another kind in color blindness, and the cure of the one is as hopeless as of the other. Any inequality in the visual acuity of the two eyes lessens the value of binocular vision, so that the more ametropic eye is readily relinquished if by so doing less accommodative effort is required. The squinting eye is generally more astigmatic than the other, but not always, for sometimes an astigmatic eye is the fixing one, while its much more hypermetropic fellow squints. It is then simply a question of choice between superior visual acuity or minimum effort, for of those which have astigmatism in one eye and higher hypermetropia in the other, some prefer distinct vision with a great effort and use the hypermetropic eye, while others prefer less distinct vision with less effort and use the astigmatic eye.

**Corneal Nebulae,** though they do not cause squint, predispose to it by lessening the value of binocular vision, and thus favor the surrender of the eye if, by that means, accommodation is facilitated or the image freed from haze.

**Congenital Amblyopia,** from imperfect development somewhere, probably plays an important part in many, if not most cases of squint and is to be distinguished from that amblyopia which, being simply due to disuse and to habitual mental suppression of the pictures in one eye, is called *amblyopia ex anopsia.*

In nearly every case of the ordinary convergent squint, no matter how amblyopic the squinting eye may be, its fundus appears perfectly normal and the macula tantalizingly perfect.

The element of the amblyopia which is due to disuse can, I think, to some extent be distinguished from the congenital element by a considerable difference in the visual acuity of the outer and the inner halves of the retina, so that if both of the surgeon's hands be held up simultaneously, one on one side and the other on the other side, while the patient looks straight forwards, the movements of the outer hand appear much more vivid to the patient than those of the inner, for the probable reason that the inner half of the retina, since it looks outwards, has been less disused than the outer half.

The same "ex anopsia" element is, of course, still more clearly demonstrated by the rapid, though generally only partial, recovery of visual acuity which attends continuous occlusion of the better eye. Even a few days makes a difference, and Javal has pointed out that if the occlusion be long continued, improvement takes place sometimes by sudden accessions, since the eye at first is not only wanting in acuity but is awkward in seeing, like a raw recruit, and this takes prolonged practice to remedy, and is sometimes overcome suddenly, as in learning to swim. Javal lays great stress on imposing monocular vision in the treatment of squint, without any intermittence, so that if on special occasions it is desired to permit the use of the better eye, the louchette should be transferred for the time being to the squinting eye.

**Development of the Fusion Faculty.**—The normal development of the fusion sense has been made the subject of special study by Claud Worth. He finds, as others have done, that from the earliest hours after birth the pupillary light-reflex is present. Indeed, the interesting fact was demonstrated long ago that both pupils respond to light incident on one eye only, and that the reflex closure of the lids upon the sudden stimulus of light is obtainable also, though the conscious perception of *objects*, so far as this can be tested by closure of the lids when an object suddenly approaches the eye, is absent during the first few weeks.* Voluntary convergence, as in watching the approach of an object towards the face, appears about the third month.

Worth has shown that the preponderance of the macular region exists at birth, since light suddenly thrown into an eye by an ophthalmoscope makes the eye immediately fix the mirror, but only for a moment. The duration of this monocular fixation increases during the first few weeks and becomes binocular at about the fifth or sixth, though still somewhat uncertainly so. During the last half of the first year of life, Worth has convinced himself by prism experiments that true binocular vision has been obtained, and that towards the end of that period the eyes will make a considerable effort in the interest of binocular vision. From the results of fusion training in the case of squinters, he concludes that the fusion faculty is fully developed before the end of the sixth year.

**Defect versus Neglect of the Fusion Faculty.**—Congenital deficiency of the "desire for single vision" is comparatively rare. It doubtless accounts for the class of alternating squints, with slight refractive error if any, in which Javal pronounced all efforts to draw out the faculty absolutely hopeless.

Worth describes these as "essentially" alternating squints, and contrasts them with the "accidentally" alternating, which only differ from monolateral squints in having approximately the same refraction in each eye. Of all constant squints, he finds fifteen per cent. are alternating.

There is reason to believe that what is largely attributed to congenital deficiency of the fusion faculty is very frequently due rather to neglected training of that faculty in the early years of life; not because of any fault in its mechanism, but because the inferiority of one eye to the other (which may be transient, as are

* Preyer, 1884, quoted by Priestley Smith.

early nebulæ, retinal hemorrhages, etc., or permanent, as in astigmatism or anisometropia), so much reduces the value of binocular vision that it is surrendered more readily in favor of any greater advantage, as, for example, that obtained by squinting in a hypermetrope whose accommodation without it is affected with difficulty. In the absence of any such advantage, binocular vision is generally retained, even when one eye is highly astigmatic. The love of stereoscopic vision is, however, undoubtedly more intense in some individuals than in others.

The easy success obtained by Worth in training the fusion faculty in so large a proportion of young squinters appears to show it had suffered from neglect more than from anything else, and it may be noticed that squinters are, as a class, apt to be naturally unobservant.

**Suppression of the False Image.**—The longer a squint lasts, as we have seen, the more difficult it becomes to elicit diplopia, because the mental habit of suppressing—*i. e.*, of disregarding—one image, becomes confirmed, and, in addition to this, the longer diplopia is absent the more difficult it becomes to re-awaken fusion reflexes.

**Depth of the Suppression.**—In cases of suppressed diplopia it devolves on the surgeon to ascertain the depth of the suppression; in other words, whether diplopia, though absent in general, can be artificially elicited with ease or with difficulty.

(*a*) If with ease, a *colored glass* held before the working eye will restore it when a flame is looked at.

(*b*) Failing that, a *prism*, edge up or down, will be more likely to succeed, by throwing the image of the flame upon an unusual part of the retina.

(*c*) Last of all, when other means fail, the rod test, made of red glass, often succeeds, if held before the working eye, and especially if its effect is heightened by a black velvet screen placed behind the source of light for contrast. Sometimes a blue or green glass held before the squinting eye assists.

**Nature of Suppression of Vision.**—Nearly every human faculty can be quickened by concentration of attention upon it and dulled by withdrawal of attention. That this is true in the domain of fusion I have shown by a simple experiment with the visual camera, described elsewhere. In recently-squinting eyes, two different objects throw their pictures on the two maculæ, but whichever object engages attention for the moment extinguishes the mental perception of the other. Indeed, the only object whose mental appeal is effectual, is the false image of the object under attention, produced by its picture, which falls on an eccentric part of the retina of the squinting eye. The same mental process which obliterates the macular picture of the squinting eye can in time extend itself to the false image as well, and always does so in young squinters with disastrous effect, for the vision of an eye thus repudiated becomes rapidly impaired (amblyopia ex anopsia). As Priestley Smith has well put it, for the squinting eye, the advice not seldom given, "to wait and see," too often means waiting and not seeing.

That part, however, of the retina of the squinting eye which answers to the extreme temporal portion of the field in a squint of low degree, is still of value in the monocular perception of objects which are hidden from the other eye by the root of the nose.

The retention of vision to a physiological amount in this extreme portion of the field, as compared with its defect in the opposite (nasal) portion of the field, constitutes a point of difference between amblyopia ex anopsia and congenital monocular amblyopia. This latter is undoubtedly rare, and when it exists is probably due to a defect of some cerebral cells rather than to the retina itself, for congenital defects of the eyeballs are nearly always bi-lateral, as witness high hypermetropia, astigmatism, lamellar cataract, coloboma, iridis, etc.

**Imperfect Central Fixation.**—When central fixation is deficient from birth in both eyes, it nearly always causes nystagmus, though not necessarily if only one eye be defective. Probably most cases of imperfect central fixation are acquired rather than congenital and, according to Javal, can even be recovered by exercise prolonged for years by intelligent subjects, and absolutely free as regards their time, though, as he says truly, the advantage gained is out of all proportion to the necessary pains.

Worth has never seen "lost fixation" in any case of squint first appearing after six years of age. The central region of the retina may suffer so much from neglect as no longer to be able to count fingers, and Worth even states that it may go so far as to have only bare perception of light within an area extending 25° to 30° from the center of the field. In congenital amblyopia *without* squint, on the other hand, he has never found the central vision lower than $\frac{6}{60}$; probably for the simple reason that had it been lower the eye would have squinted, from binocular vision being of so little value. The earlier squint commences, the more rapid is the progress of the blindness, provided it be monolateral, and Worth states that at the age of six or eight months the power of central fixation is often lost within eight or ten weeks. When a squinting eye has lost its fixation power it either wanders indefinitely, when the fixing eye is covered, or tries to fix with some part of the retina around the fixation point; or, as a third alternative, it may squint still farther inwards to use the temporal part of its field, which has still retained the exercise of its functions (eccentric fixation). The highest vision possessed by such eyes is to count fingers at 3 or 4 meters (Asher), and Alfred Graefe says that often greater visual acuteness is obtained when the test objects are held in a line with the macula of the deviated eye, in spite of the fact that from sheer want of habit the eye does not move so as to use its macula.

**Its Diagnosis.**—Defective central fixation is easily diagnosed by making the patient cover his good eye and try to fix the sight-hole of the ophthalmoscopic mirror with the amblyopic eye (Priestley Smith). The corneal reflexion, instead of occupying its steady and proper position, will appear to wander about. As akin to this defect Javal notes a certain number of cases in which there is a *trembling* of the *image* seen by the defective eye, even after the power of simultaneous vision by the two eyes has been restored, just as a weak hand trembles more than a strong one. I have noticed this too, and it is not infrequent.

**Newly-Acquired Field of Fixation** (Perverse Projection, or Strabismus Incongruus, of Graefe).—It occasionally happens that in squints of unusually fixed amount, which began in early life, the squinting eye has so far accommodated itself to its new conditions as to project objects in accordance with the working eye, so that a kind of second-rate binocular vision is retained. On putting such an eye straight by operation, crossed diplopia of high degree immediately appears, which fades away in time. It is not, of course, the eye itself which projects, but its cerebral center; so that the name, "false macula," often given to this condition, is a fallacious one. It is doubly fallacious, since it is not a macula that is called into being, but a new *field*. It has been wrongly described as a small part of the retina which has retained its function in virtue of receiving companion images to those received by the macula of the best eye. Were this view correct, there would be no post-operative diplopia, for diplopia means two images of the same object, and the supposed solitary functionating spot of the retina cannot, when displaced by operation, receive a second image from the same object as the good macula.

The diplopia observable is that of images received upon the two true maculæ, but the whole field of the squinting eye having been cerebrally displaced for many years, its macular impressions share the displacement as much as all other parts of its retina. In rare cases objects of similar appearance placed in line with the two foveæ may be seen close together, as well as in the form of crossed images far apart. It is evident, therefore, that in consequence of the squint, the faulty eye has acquired a new projection without entirely forgetting the old. Javal's view is that there may have been fusion of the fields of the two eyes, with mental suppression in the case of each of the part which corresponds to the field employed by the other, since it is generally not until after operation in these cases that there is any complaint of spontaneous diplopia at all, and it is sometimes even difficult to elicit it before operation by red glass before one eye and a candle.

**Strabismus Convergens Myopicus.**—In myopia of not very high degree, and in which the value of the two eyes is too equal to make it seem desirable to their possessors to surrender either, a strong *effort* of convergence (relatively to accommodation) has to be made in near vision, since the converging innervation is so unsupported by any effort of accommodation, and the difficulty arises from having to strongly assert one, and restrain the other, of two cerebrally associated innervations. This relatively strong converging activity, exerted for long periods at a time by those who are engaged in reading or near work, cannot always at once be easily surrendered when distant objects are looked at, and thus esophoria in distant vision becomes developed in consequence, gradually increasing as its cause continues till homonymous diplopia threatens, then appears, persists and increases. In near vision the diplopia is less, and may even give place to slight exophoria. A certain proportion of these cases, if concave lenses and prisms do not relieve them, are grateful for operation, if care be taken not to create insufficiency of convergence in reading.

**Deficient Abduction of the Squinting Eye** is found not only in cases of paralyses of the sixth nerve, but also in ordinary concomitant convergent squint under certain circumstances, though as a rule the restriction in outward movement is considerably less than the amount of squint.

When the restriction is very marked, it is natural to suppose the primary cause to have been an affection of the sixth nerve, and if there be any corresponding want of concomitancy, the supposition is, without doubt correct : it may even be correct when concomitancy exists over the whole motor field up to the area of restriction, for though the concomitancy shows that the nerve has recovered its power, its paralysis may have been the original cause.

But in many cases the restriction is simply due to *want of habit*, and has no pathological meaning. It is when the squinting eye is highly amblyopic in all parts of its field of vision and when, therefore, the amblyopia existed from infancy and preceded the squint, that this explanation is most probable, there being then no object gained in turning the eye outwards. Secondarily, perhaps, the rectus may be weak for want of use ; but this corrects itself, I believe, in time if the eye is brought into use.

If the deficient abduction be due to defect of innervation, instead of tenotomizing the internal rectus of the squinting eye that of the sound one should be divided, so as to call the defective innervation into play. It is sometimes better, however, to advance the external rectus of the squinting eye.

When restricted abduction is really due to an evident defect of the sixth nerve, advancement of the external rectus is the only justifiable operation, reinforced, if needed, by tenotomy of the internus of the same eye.

A very useful adjunct to tenotomy I find to be *stretching the soft cicatrix* if a greater effect is desired. It can be done daily for several days after the operation. The way I proceed is as follows : After pressing a small plug of cotton wool dipped in cocaine solution and held by fixation forceps, against the conjunctiva close to the outer margin of the cornea, the conjunctiva is tightly gripped and the eye drawn slowly and steadily out while the patient fixes with his other eye an object on the other side of the room. The eye is then held in this position of divergence for about a minute, during which it yields a little more. The idea was suggested by the so-called "mechanical" treatment of squint by stretching the muscle without operation, of which, however, I have no experience, as it does not sound a practical idea.

**Divergent Strabismus.**—The eyes when free from active innervation tend to settle down into divergence. Healthy eyes diverge under chloroform and during sleep, and even the so-called "permanent" element of a convergent strabismus may completely disappear under the chloroform. This seems to confirm Donders' view, that while the development of convergent squint is an active, that of divergent squint is a passive process.*

With a few, sometimes rather inexplicable exceptions, blind eyes in emmetropic individuals tend to diverge, especially in adults. The exceptions consist of those who had esophoria previously, either from weakness of the external recti, from anatomical anomalies of the ocular muscles, from ciliary paresis, or from habitual over-tonicity of the converging innervation.

**In Myopia.**—While there may be some truth in the statement that the elongated shape of myopic eyes opposes an obstacle to convergence, the want of support to convergence due to the absence of accommodative effort, is no doubt the chief cause of that myopic exophoria in near vision which often exists to so high a degree, even in eyes of equal refraction.

The higher the myopia the greater is the effort of convergence in reading or fine work, and this effort being unsupported by its companion innervation may cause sufficient fatigue of the converging center to allow at times one eye to deviate. If it does so at all, it does so considerably, so as to minimize the trouble occasioned by the diplopia. When once the habit has commenced, it gains in frequency and may lead to a permanent squint in both near and distant vision. The treatment in the early stages is evidently to correct the myopia in whole for young people or in part for older ones, so as to lessen the convergence and introduce at the same time an act of accommodation.

**With Anisometropia.**—When any considerable difference exists between the value of the two eyes, the effort of convergence may be greater than the usefulness of the worst eye, which the patient, therefore, at times allows to deviate outwards by discontinuing the converging effort, especially if he finds that by so doing accommodation can be more completely relaxed, or if the print, as seen by

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* Donders' antithesis is: "Hypermetropia causes accommodative asthenopia, to be actively overcome by strabismus convergens. Myopia leads to muscular asthenopia, passively yielding to strabismus divergens.

one eye, is more distinct than when seen by both. As Javal points out, binocular vision has less value for reading than for most other acts of vision, since in a page of print there is no "third dimension." For this reason habitual latent divergence (or "suppressed" squint) is all the more apt to give place to "manifest" squint on occasions which becomes more and more frequent, until it persists altogether, and involves distant vision as well.

**Age Relation.**—While, therefore, convergent squint is of infantile origin, the divergent variety commences towards adult life. This is due to the fact that children are so rarely myopic, and to the adolescent increase of myopia. The practice of steady reading, too, increases in the years of adolescence. And again, as mentioned elsewhere, the tonic activity and excitability of the converging center seem to lessen with age, which also favors divergence.

**Refractive After-Treatment for Squint.**—Over-correction of *convergent* squint is generally advantageously followed by either no correction or a considerable under-correction of any existing hypermetropia, and it is sometimes, I think, a good plan to make young emmetropes wear even weak concave lenses.

On the other hand, operative *under-correction* of a *convergent* squint clearly indicates full correction of the hypermetropia in distant vision and perhaps even an over-correction in near vision, in order to gradually supplement the effect of the operation.

*Operative over-correction* of *myopic convergent* squint should be followed by constant use of the full refractive correction.

*Over-correction* of *divergent* squint, if it remains, interposes a serious difficulty in the restoration of binocular vision, because a diverging effort is much more difficult to make in the interest of fusion than a converging effort. Stronger plus lenses, or weaker minus ones, are therefore indicated.

*Under-correction* of *divergent* squint indicates weaker plus or stronger minus lenses.

The above rules, it need hardly be said, apply only to the "post-operative" treatment of squint, *i. e.*, after everything has been done that is indicated in an operative way; and they are only intended to give the "fine adjustment" at last. For every operator knows that after putting a squint straight to the perfect satisfaction of the patient, the effect is generally either a trifle less or a trifle more than his own ideal. It is true that when binocular vision is restored the defect is entirely covered, and exists only as a "heterophoria"; but there it is, all the same, and a slight modification of the optical correction, when the patient is (as usual) young enough not to mind it, can either increase or lessen the activity of the tonic convergence, so as to correct by degrees even that heterophoria. Thus, with residual "esophoria," a low hypermetrope might dispense with glasses altogether for a time, and a high hypermetrope wear a somewhat weaker pair. There is no need to make the modification a great one, so long as it is in the right direction. Nor, of course, is optical adjustment intended to take the place of fine second operative adjustment in the event of the first operation being markedly insufficient. It is essentially "post-operative."

In long-standing convergent squints, where the restoration of binocular vision is impossible, perfect straightness is to be regarded as undesirable, since it leaves no margin for the natural diminution of converging activity, which goes on year after year. In such a case, therefore, a slight reduction should be made from the full hypermetropic correction, unless the patient be willing for another slight operation a year or two later on. At least three degrees of residual convergence should be aimed at in cases where binocular vision is irrecoverable, and, thanks to the high angle gamma, which generally exists in hypermetropes, the eyes do not betray a residuum of even five degrees to ordinary observers.

**Author's Combined Bar-Reader and Squint Stereoscope.**—This instrument is intended to be placed in the hands of a patient. A saw-cut is made round the lenses of a Holmes stereoscope and two hinges put on, so that the lenses can fall down out of the way when the instrument is used for bar-reading. Two pieces of talc or mica are pivoted into saw-cuts and are scratched by gentle gradation more and more from their inner or lower edge to their outer edge. By gradually lowering one of these before the non-squinting eye, its vision is gradually lessened till the image that belongs to the squinting eye springs into view.

Another plan is to begin with the talc shutter down, and while the squinting eye is examining some near or distant object, to gradually allow the good eye to be uncovered, while still trying to keep the squinting eye in use. In this way a monolateral squint can be readily trained to be alternating. For bar-reading, the oval containing the lenses should be turned down on its hinges. Another new feature of the instrument is that it is provided with an extensible median partition, which stretches from the middle of the card to between the two lenses.*

**Natural Cure and Natural Increase.**—Convergent squints become gradually less as years go by. In the case of young children this is partially due to the physiological growth of the eye causing diminution of their hypermetropia, its exciting cause. But, besides this, the converging center appears to lose its excitability with age, and even squints in which no hypermetropia at all is to be found, tend to get less in course of time. Divergent squints, however, generally get worse as years roll on.

**Treatment of Fixed Convergent Squint.**—We have seen that convergent squints tend in the course of years to undergo a natural cure. The correction of any hypermetropia, or hypermetropic astigmatism, of course, expedites this natural cure and should always have a good trial, except in squints of very high degree, in which the patient might have to wait many years and thus lose the likelihood of regaining binocular vision. In such cases a good plan is to wear glasses for six months, and if the squint is found, by measurement before and after, not to have notably decreased, an operation should be performed, so as to lose no more time. In the mean time, steps should be taken to lessen amblyopia in the squinting eye, by occlusion of the good one, and to recover any lost faculties by training.

Since, however, it is easier to lose faculties than to regain them, it is important, as emphasized by Javal and Priestley Smith, to commence the treatment of squint at as early an age as possible. Refraction should be corrected, or, if that be impracticable, atropine may be used continuously for a time in the best eye if the squint be unilateral or in both if it be alternating. The effect of atropine should be watched, so as to discontinue it if it does not markedly diminish the squint. Occlusion of the squinting eye (Buffon, Javal) is better still. Personally, I am not much in favor of atropine for continued use. Both Javal and Priestley Smith speak of operating as early as two years of age, if necessary. To do this we must first feel confident about the certainty of restoring binocular vision, otherwise the eye will turn out in later life. With congenital squints we cannot have this confidence, and it is wise to approach them with caution; but when there is a definite history of the squint having been preceded by straight eyes, with an interval during which it was periodic, and especially if we can still elicit

* The instrument can be obtained from E. Long, Tangley, Bournemouth, England.

diplopia or excite fusion by stereoscopic devices, an operation can be done without fear.

**Recovery of Lost Faculties.**—Javal has been the chief pioneer in this direction. The steps in cure, according to him, are :

(1) Restoration of the power of *simultaneous vision*, as evidenced by *diplopia*, by overcoming the habit of suppressing the image of the faulty eye. The chief agent to this end is the permanent monocular occlusion.

(2) Overcoming this diplopia by *fusion*. For this the stereoscope is useful, and also exercises without the sterescope, with flames and prisms arranged to excite the desire to see single. For convergent squints of high degree, Javal uses Wheatstone's stereoscope.

(3) The perception of *relief* by suitable motions of the eyes. For this the stereoscope may again be pressed into service. The length of time required to re-establish binocular vision, according to his experience, is nearly equal to that which has elapsed since the squint began.

Let us look at these in detail.

*Occlusion.*—The object of this is to overcome the mental suppression of the false image. Javal's idea is to have either one or the other eye *always* covered, so that more than one image at a time is never seen, in the hope that the brain will forget how to suppress the second image. It is best to cover the good eye, but, as a luxury, the cap may sometimes be transferred to the squinting one. Few oculists pursue this treatment so completely as Javal recommends ; occlusion for a few hours a day is a more common prescription but not nearly so effective. To equalize the vision of the two eyes I sometimes prescribe a deeply-tinted glass before the better one, with one or two opaque bands across it.

*Orthoptic Training.*—Javal's cartons contain numerous devices and are of great service. They are intended for use with either an ordinary stereoscope or (if cut in two) with a modification of a Wheatstone stereoscope, arranged by Javal under the name of a "sterèscope à charnière." As a preliminary to stereoscopes, however, I prefer to use a very simple device lately introduced by Priestley Smith and to which he has given the name of "fusion tubes." They consist of two short tubes, held together by chains, for the squinter to look through. Each is provided, at the eye end, with a convex lens whose focal length is equal to the length of the tubes, and the other end is closed by an opaque disk perforated with two translucent holes. The hole in the center of each disk is white, while the neighboring hole is red in one tube and green in the other. On looking into these tubes, a squinter with binocular vision sees four holes, two of which are white, one red and the other green. By moving the tubes, the two white holes can be brought together and fused. Three holes only are then seen, red, white and green. The red and green holes act like Javal's "control marks," to insure that true fusion exists and not merely suppression of images by one eye. By now moving the tubes so as to slightly separate the white holes and thus making a strong cerebral effort to fuse them, the eyes can be trained to overcome a squint.

The great quality required is perseverence, and when I have been able to meet with it, the fusion tubes have proved very successful. One nurse maid, for instance, with a periodic divergent strabismus of 15°, restored her eyes to perfect orthophoria in three months. A boy with more than 5° of vertical squint restored his eyes to parallelism within the same time. Fusion tubes mounted in a more elaborate way, so as to measure the squint, constitute the heteroscope of Priestley Smith. By affixing translucent gum paper to the farther end of the fusion tube before the better eye, the holes seen by that eye can be darkened. This enables the other eye to see better. Landolt has introduced a stereoscope to facilitate this plan, in which similar tubes are used, but pictures are employed and the farther end can be darkened by an iris diaphragm. I do not know if Tourmaline plates have yet been suggested, but they would doubtless act very well. Quite recently C. Worth, of London, has brought out an arrangement of tubes which, in principle, is as if the "sterèscope à charnière" were mounted in tubes, with translucent pictures mostly like Perlia's, intended to be unequally illuminated by lamps placed opposite the two tubes. By lowering the lamp before the good eye, the picture before the other eye becomes visible. The instrument promises to be useful for squints of higher degree than the fusion tubes can suit and has the advantage of permitting any number of designs. When an ordinary stereoscope is available, Perlia's excellent pictures may be used.

**Magnetic Stereoscope.**—This is a new apparatus which I have constructed and which appears likely to be very effective. The patient looks into an ordinary stereoscope fitted with small electromagnets which move a black feather at the end of a straw, so as to cut off the vision of either eye at the will of the surgeon, who sits in a chair at any convenient distance and presses a button on a separate piece of wood to occlude the right eye or another button to occlude the left. The movement of the feather is almost instantaneous. By interposing an interrupting hammer in the circuit or a metronome with a wire across its lever, the two ends of which dip alternately into pools of mercury, the work of the surgeon can be done mechanically. The apparatus can be used in several ways. One of Javal's cartons is placed in the stereoscope, such as an L before one eye and an F before the other, or a pictorial representation of a stable before one eye and a horse before the other. Any one of the following plans can be adopted :

(*a*) By intermittent occlusion of the fixing eye alone in a case of deep suppression of the false image, the latter comes into view. By degrees the intermission can be made so rapid that the true image is not lost at all, and thus both images are seen simultaneously.

(*b*) The feather can be made to occlude each eye in turn, at first slowly and then more rapidly. This keeps both eyes "alive," as it were, and incites them to act more and more simultaneously.

(*c*) With the good eye occluded, the briefest possible uncovering of it may be made, before and during which the patient is told to carefully watch the image before the suppressing eye so as not to lose sight of it. The interval can then be lengthened by degrees. The apparatus was suggested by some physiological experiments I made with the visual camera about seventeen years ago, but I have only recently applied it clinically.

**Extension of Partially-Preserved Faculties.**—The slightest retention of binocular vision in comitant squints affords a very encouraging factor in prognosis and squints can be approached for operation with far more confidence if it exists, since, once restored, it has a keeping power which prevents the return of the squint as well as the power of perfecting the straightness of the eye utterly beyond any operative ability. For this reason, operations for unilateral strabismus should be preceded by at least a month of permanent occlusion of the better eye, if there is any hope of restoring binocular vision.

In incomitant squint, when binocular vision still remains in no matter how small a corner of the field, its extension by judicious operation is feasible, and even without operation it may be extended, as Javal suggests, by daily training in which the patient fixes some bright object with great attention while slowly moving his head so as to bring the vision of it to the furthest limits of his field of single vision.

**Evidences of Squint.**—The most decisive evidences of a squint are diplopia and the appearance of a manifest deviation of one eye. The diplopia may, however, be missing, from blindness of one eye or from the habit of mentally suppressing the false image, and the deviation may be apparent rather than real. This makes it necessary to have tests at our disposal to make sure.

**Exclusion Test for Squint.**—As this useful old test is frequently spoilt by the student too indefinitely shifting his hand from one eye to another, it may be well to describe it minutely.

Direct the patient's attention to some small and rather distant but perfectly distinct object, and after ensuring, by watching his eyes for a moment or two, that his gaze is steadily fixed, suddenly cut off the vision of one eye—say the right—by a swift lateral movement of the left hand, made from the wrist, with the fingers extended and the dorsum towards the patient's eye, but without touching any part of his face. If the left eye make no corrective movement but remain as immobile as ever, it is acquitted from squinting.

But the excluded eye is not yet acquitted, for it may be the squinting one; therefore, now, after waiting again a moment or two to ensure that the patient is steadily fixing, cover his left eye suddenly with the right hand. If the right eye remain immobile, it also is innocent. No squint, therefore, exists.

If, however, either eye should make a little *inward* "corrective" movement when its neighbor is covered, it must have been previously squinting *outwards*, and if it make a little *outward* "corrective" movement, it must have been previously squinting *inwards*.

The test for manifest squint must be distinguished from the exclusion test for suppressed squint, described later, in which the procedure is entirely different.

*Manifest* squint is that which exists when both eyes are naked.

*Latent* or "suppressed" squint is that which only arises when one eye is excluded from vision, or is in some way dissociated from its neighbor.

**Subjective Screen Test.**—The following is translated from Alfred Graefe :

"Suppose, for example, that, on account of paralysis of any muscle of the right eye, slight deviation of the visual axis is present for some determined position of the object. If we now cover the right eye during fixation, the image of that eye will disappear and that of the left retain its position, since the sound (left) eye, engaged in fixation, will continue undisturbed therein.

"Let us, however, under similar conditions, cover the left eye ; its image will correspondingly disappear, but simultaneously the still remaining image of the right eye will exhibit a change of position, since the right eye now for the first time directs itself for fixation and has to make a proportionate excursion to bring its hitherto eccentrically-placed retinal picture to the spot of central vision."*

**Secondary Deviation.**—When we compel a squinting eye to take up fixation by placing a screen, such as the hand or piece of ground glass, before the eye which naturally fixes, the squint is transferred from one eye to the other, and the deviation of the eye behind the screen is called the "secondary deviation," to distinguish it from "primary deviation," which is the deviation of the squinting eye under ordinary conditions.

In *alternating squint*† we have seen that the transference of the squint from one eye to the other remains after withdrawal of the screen, one eye being as prone to squint as the other and the patient having no preference as to which he uses for fixation. With alternating squints, therefore, we cannot draw any distinction between primary and secondary deviations : in these cases it will generally be found that there is great approach to equality in the visual acuity of the two eyes.

In *unilateral* squints, the secondary deviation gives place again to the primary as soon as the screen is withdrawn, the squint being again transferred to its original seat.

It is easy to observe the relative amplitude of the two deviations, for the extent of the secondary deviation can be watched through a piece of ground glass (Javal) or even behind an opaque screen, if the latter be held obliquely so as to let the eye be visible

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* Alfred Graefe ; "Motilitätsstörungen" (1858), p. 21.

† There is a large intermediate group of cases which are nearly alternating, the patient being able to fix with either eye but preferring one above the other. In these cases the secondary deviation remains for some time after withdrawal of the screen.

while yet it is cut off from fixation ; or, better still, the hand can be withdrawn instantaneously long enough to see the deviation without giving it time to disappear.

When there is the slightest *paralytic* element in the squint the secondary deviation is infallibly greater than the primary, and the more so the more the direction of fixation becomes such as to require contraction of the affected muscle.

An extremely delicate test, therefore, for paresis is to test the secondary deviation at the extreme periphery of the motor field in the direction of action of the paralyzed muscle.

In *comitant squint* the primary and secondary deviations are equal and the amplitude of the squint remains unchanged over the whole motor field, except sometimes near its periphery from mechanical hindrances : this kind of squint is due to anomaly of a conjugate innervation.*

**Persistent Secondary Deviation.**—It sometimes happens that in a patient affected with paresis of an ocular muscle, the affected eye has so much the better vision of the two that he prefers to use it for habitual fixation. In this case he goes about with a "persistent secondary deviation" of the unparalyzed eye, which may deceive a careless investigator and make him blame the wrong eye. Such cases are somewhat rare, however, for the paralyzed eye can only be used at the cost of giddiness, malprojection and unsteadiness, to reduce which to the minimum the patient goes about with his head so inclined as to give the weak muscle as little work to do as possible.

**Reason of Secondary Deviation.**—It remains to explain *why*, in paralytic squint, the amplitude of the secondary deviation is greater than that of the primary. It is simply due to the fact that no considerable† impulse can travel to any muscle without an equal impulse being sent to its associated muscle in the other eye. The normal eye faithfully responds to its received impulses and moves in exact proportion to their strength, but the paralyzed muscle is unable to respond in the same proportion, if at all. When the squinting eye, therefore, is compelled to take up fixation, half of the great effort required is vainly spent on the weakened muscle, while the other half produces a high degree of movement in the normal eye—a degree which measures the amount of effort put forth.

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*Cases of non-paralytic squint I have met with in which the secondary deviation is distinctly greater than the primary. In others, especially with *H.* or *H. As.*, the reverse may be the case, from want of visual effort in the squinting eye.

†I say "considerable," because in the interests of fusion the eyes can in a small degree adjust themselves in a way which does not *seem* to obey the laws of conjugate motion.

**Fallacy from Anisometropia.**—There is one fallacy to be guarded against in testing the secondary deviation : if one eye be more hypermetropic than the other, the secondary deviation may be greater or less than the primary, owing to the greater amount of accommodation required from one eye, producing a proportionately greater amount of associated convergence.

**Apparent Squint.**—The appearance of squint, as has been said, may be illusory. Myopic eyes frequently give the impression of a

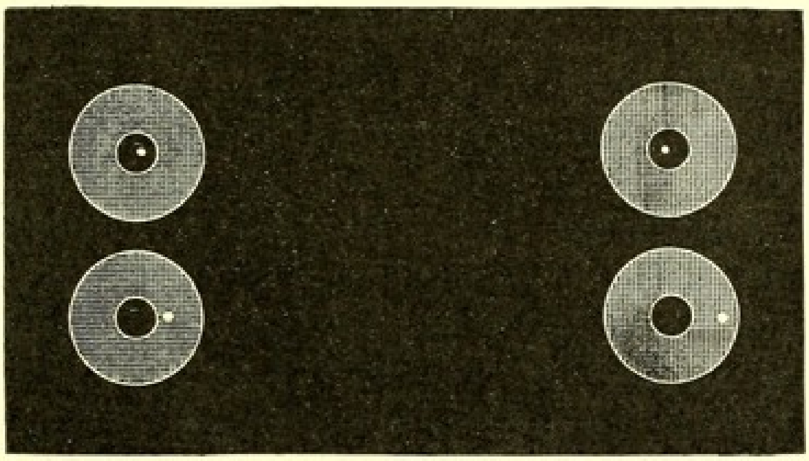

**Fig. 45**

Ophthalmoscopic corneal reflections in Emmetropic eyes; (*a*) with both eyes looking at the center of the mirror (*b*) with both eyes looking to the right, showing asymmetry of the corneal images owing to the angle alpha.

slight convergent squint, while, on the other hand, hypermetropic eyes, though not quite so deceptively, often appear divergent.

We can settle any doubts in our mind as to whether the squint is a real one, by the "exclusion test," already described ; or, better still, by placing the patient with his back turned three-quarters towards the window ( or with his head near a flame, if the room be dark), and reflecting the light on to first one eye and then the other from the mirror of the ophthalmoscope, held about nine inches from the face. The observer should look through the aperture of the ophthalmoscopic mirror as if about to examine the patient's fundus, *and also direct the patient's attention carefully to the same aperture.* A tiny circular reflection from the mirror will now be visible in each eye, as in Fig. 45, about $\frac{1}{60}$ inch in diameter, but smaller still the farther away the mirror is held.

In emmetropic eyes the reflection will appear, as in the figure, slightly to the inner side of the center of each cornea, and if they are symmetrically disposed in the two eyes, the existence of squint may be safely denied.

If the deceptive appearance has been due to myopia, the reflections will lie nearer than usual to the center of each cornea ; but if to hypermetropia, they will both appear displaced farther inwards than usual. The fuller treatment of this subject in a subsequent chapter makes it unnecessary to pursue it much further in this one.

**Intrinsic Aberrations.**—In the eyeball itself are :

(1) *Angle alpha of Donders.*—The angle between the antero-posterior axis of the eyeball (which Donders assumed wrongly to coincide with the axis of the cornea) and the visual line. Variations of this angle cause deceptive appearances of squint.

(2) *Angle alpha of Landolt.*—The angle between the visual line and the major axis of the corneal ellipsoid. This angle contributes nothing to a deceptive appearance of squint.

(3) *Angle gamma.*—The angle between the antero-posterior axis of the eyeball and the fixation line. This angle differs but slightly from the last, since the fixation line so nearly coincides with the visual line and therefore has a bearing on apparent squint. The fixation line proceeds from the point of fixation to the center of motion of the eyeball. The visual line also proceeds from the point of fixation but to the anterior nodal point.

**Linear Strabismometry.**—This method of measuring squint has almost died out of use. It took account of the linear displacement of the pupil and was, at one time, the popular method, owing to Graefe's view that a displacement of the pupil, measured by so many lines or millimeters, could be rectified by setting back the tendon by an equal number of lines or millimeters. In practice, however, this has been found to be impossible, and Landolt pointed out that, owing to the different lengths of different eyes, an angular measurement was the only rational one.

Nevertheless, the linear method did good service in its day, and flat pieces of ivory with a concavity to fit the lower lid are still to be met with, being relics, more or less faithful to the original, of Lawrence's strabismometer, once much used in England. The concavity is graduated in millimeters from a central zero and is intended to be used in this way : Place the patient facing the window and, with the good eye covered, direct his attention to some distant object. Place the zero of the scale just under the pupil of the now straight but usually squinting eye, and then uncover the better eye : at once the squinting eye asserts its habit and the figure which now lies under its pupil measures the squint. The relation between angular and linear measurements may be expressed by saying that each millimeter along the sclerotic means about 4½° of squint.

**Hirschberg's Method.**—A lighted candle is held one foot in front of the patient's face, the surgeon placing his own eye near to the candle and looking just over it at the eyes of the patient, who is made to look at the candle. The position of the corneal reflection on the squinting eye indicates roughly the amount of squint. Since the breadth of the cornea is about 12 mm., a squint which brings the reflection to the margin of the cornea is one whose linear measurement is half the diameter of the cornea, namely, 6 mm. Half this displacement means a squint of 3 mm., and so on. Hirschberg points out that a 6-mm. squint in which the reflection occupies the margin of the cornea, means one of about 45°, while one in which the reflection occupies the margin of a medium pupil, is about 15°.

Owing to the angle gamma between the optic axis and fixation line, which the Hirschberg method neglects, a reflection situated over the outer margin of an average pupil, means a greater and sometimes a much greater squint than a reflection situated over the inner margin. Nevertheless, Hirschberg's method, as far as it goes, is a very useful one and often enables an excellent *guess* to be made, provided the precaution be taken to keep the surgeon's eye, the flame and the *squinting* eye in one straight line. If not quite so accurate as the use of ophthalmoscopic corneal images, which were introduced at a much later date, it is nearly so, and it possesses the advantage that "lights" are generally found more readily than ophthalmoscopes. For the more exact measurement of squint, however, one of the following methods is necessary :

**Perimeter Method.**—This mode of measurement assumed sway as soon as the linear method began to wane and, in the manner recommended by Javal, has been greatly used, its advantage being its accuracy, and its two disadvantages lying in the absorption of time by the preliminary arrangements and in the difficulty of measuring slight convergent squints by it, since for them the surgeon's head interferes with the fixation line of the sound eye.

The patient should be seated so as to bring the squinting eye (*S*, Fig. 46) into the center of the perimeter, while straight in front, at a distance of five meters, is placed a candle for the fixing eye *F* to look at. It is only some perimeters which permit this.*

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*The useful addition to the perimeter, introduced by Landolt and now become general, namely, a piece of soft wood to be gripped by the teeth, is very useful for strabismometry.

Another flame, or, better still, a small electric light, is then moved along the arc of the perimeter, with the surgeon's eye ever behind it, till its reflection appears to occupy the center of the cornea or rather that part of the cornea which our knowledge of the angle gamma leads us to select and which I have called elsewhere the "fixation-position" (Chapter XI). The squint is now measured by that figure on the perimetric arc which lies against the flame.

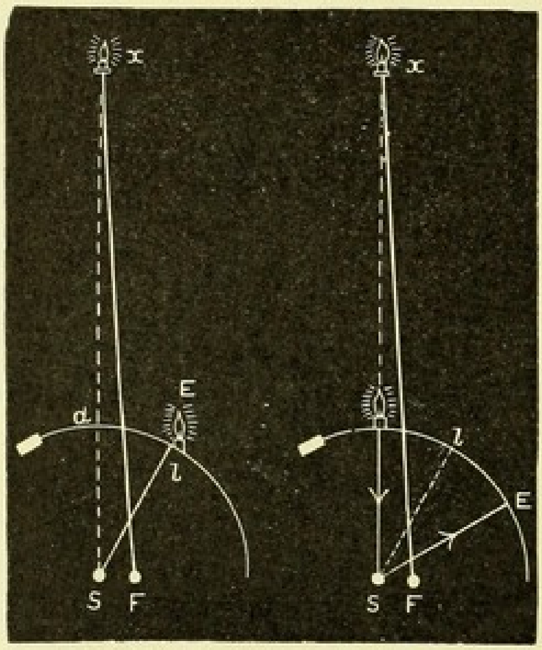


**Fig. 46** Javal's method. **Fig. 47** Charpentier's method.

For great accuracy the angle gamma can be measured separately by screening the good eye and making the squinting one fix the ivory disk of the perimeter while a flame (with the surgeon's eye kept strictly in line behind it) is moved along the arc till its reflection appears to occupy the exact center of the corneal circumference. The figure reached by the candle enables the angle gamma to be at once read off from the perimeter. This angle should be subtracted from the record of a convergent squint, and added to that of a divergent, premising, of course, that they have been measured by the center of the cornea.

In the figure, *d* is the ivory disk of the perimeter, and were there no squint, the visual axis of the left eye would pass through this, as shown by the dotted line. The angle *d S l*, therefore, is the angle of the squint and is measured by the arc *d l*.

By bringing the distant flame nearer to the perimeter the squint can be measured under different accommodative conditions; or, finally, the ivory disk may itself be made the object of fixation.

The figure makes evident, also, how in a squint of low degree the method is rendered impracticable by both the flame *E* and the surgeon's head behind it, interfering with the vision of the distant flame by the fixing eye *F*.

**Charpentier's Method.**—The difficulty just spoken of is evaded in the plan illustrated in Fig. 47, where advantage is taken of the law that angles of incidence and reflection are equal. The flame is placed over the fixation spot of the perimeter, and the surgeon's eye is made to travel along the arc till its reflection appears to lie in the center of the cornea of the squinting eye. The squint is then measured, its angle being *half* the angle of the arc.

One little fallacy in this test seems to have escaped notice, and is illustrated in Fig. 48. Owing to "spherical aberration," the image formed by reflection from a convex mirror alters its position with every change in the angle of incidence and its ever equal angle of reflection, so as to lie on the caustic curve shown in the figure. This caustic curve is one whose cusp *F* lies in a line drawn from the center of curvature *O* of the cornea parallel to the incident pencil *i*. By producing the reflected pencil *r* backwards till it meets the caustic curve at *F′* the position of the image is found.

Moreover, secondly, the surgeon judges by its projection against the plane of the iris, not against the center of the cornea; so the while the image lies at *F′* on the caustic curve, it is projected on to the plane of the iris, where it clearly would appear eccentric.

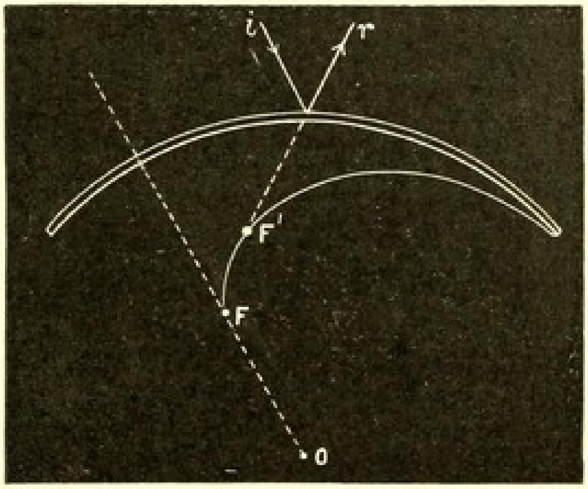


**Fig 48**

Section of Cornea, to show that light reflected from the center of the cornea symmetrically does not produce an image in the optic axis, but rather to one side of the center of the pupil.

In the absence of a candle, a circle of very white paper, mounted in the perimeter, gives a recognizable reflection from the cornea, and this, indeed, has been utilized in De Wecker and Masselon's "Arc Keratoscopique," which also has a little mirror in which the distant object is reflected which serves for the point of fixation. It seems superfluous, however, to have a special apparatus for strabismometry, if instruments already in possession for other purposes serve as well. To any who think otherwise, the "arc keratoscopique" will be found very handy.

Priestley Smith's tape method will be found described in the chapter on "Ophthalmoscopic Corneal Images."

**The Tangent Strabismometer.**—The tangent scale (latest edition best) constructed by the author for use with his rod test is the only apparatus needed, and since it hangs on the wall, it occupies no space in the room and is ever ready. It is in principle a flattened-out perimeter, but has the advantage over the perimeter of being time-saving. An immense number of squints are operated on without being measured in degrees simply for want of time, and the tangent strabismometer is meant to meet this difficulty. It serves

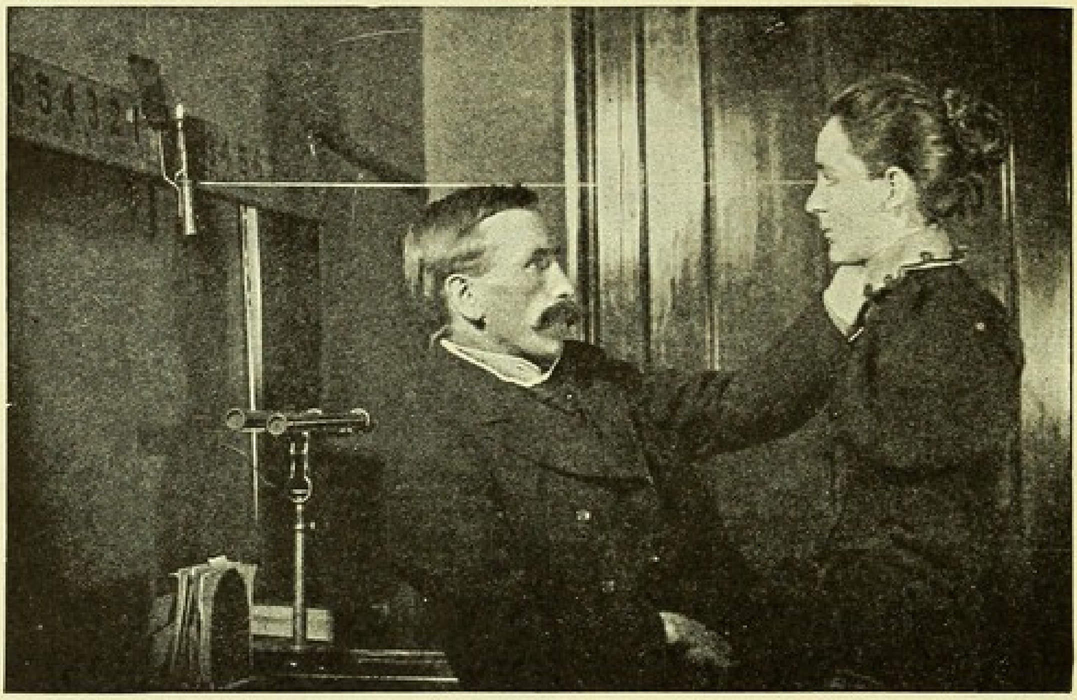

**Fig. 49**

First step in tangent strabismometry ; adjusting distance of patient by a meter-string.

for both the objective and the subjective measurement of squint, and whenever diplopia can be elicited, both kinds of tests should be made ; for while, on the one hand, subjective measurement is far more delicate than any objective measurement could possibly be, on the other hand there is the chance of meeting with one of those occasional fallacies in the projection of the false image, which need checking by the rougher though more dependable objective observations.

The *large* figures on the tangent scale are not intended for ordinary strabismometry, but rather for latent deviations or slight squints (under 10°), since they represent degrees for a distance of 5 meters. The row of *smaller* figures is added for strabismometry and, being intended for use at one meter, since they mark degrees at that distance, a piece of string one meter long hangs from the candle ready to adjust the distance of the patient.

**Mode of Use.**—Placing the patient facing the candle, at the meter distance, the surgeon introduces his own head between the two, but a little lower down, about a foot away from the patient and so that the root of his own nose is vertically under the rays of light which proceed to the patient's eyes. At once the tell-tale corneal reflections reveal which eye is the squinting one, and the amount of squint being guessed at by the degree of eccentricity of the reflection, on Hirschberg's principle, the patient is told to look at the figure which numerates the guess.*

If the guess of the amount of squint, as revealed by the corneal reflections, be true, the squinting eye has been brought straight for the candle and the reflection upon it occupies its proper position.

If the guess be only partially correct, successive figures are mentioned, one by one, for the patient to look at, till the surgeon is satisfied as to the right one. For rapid work this suffices and takes scarcely more than half a minute. Since the height of the patient is immaterial, no time is lost in adjusting it, as in the use of the perimeter.

Greater accuracy still may be secured by screening the working eye and making the squinting one fix the flame for a moment to see what the *fixation-position* of the corneal reflection is and whether it is similar to that of the working eye.

(1) *Concomitancy* can be measured by repeating the observation with the patient's face turned to one side and the other (Berry).

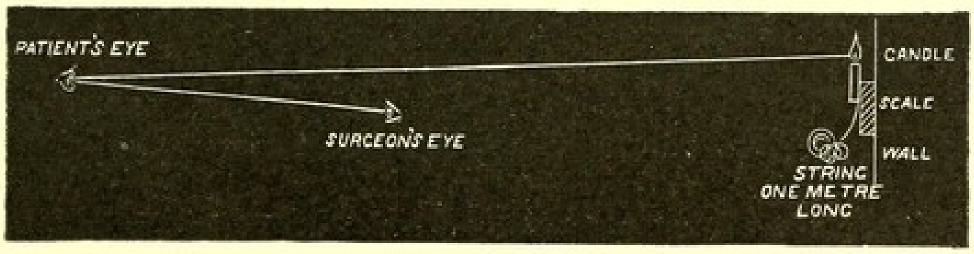


**Fig. 50**

Tangent Strabismometry. To show the path of the light from the candle.

(2) The *secondary deviation* can be measured by screening the working eye and making the squinting eye (and the face) look at a figure which brings the working eye straight for the candle, as proved by momentary unscreening to look at the corneal reflection; or by a little adeptness the working eye can be screened from the figure looked at by the other eye, yet not from the flame.

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*According to Hirschberg, when the reflection occupies the margin of a moderate-sized pupil there is about 15° or 20° of squint; when the margin of the cornea, about 45°. For divergent strabismus the figures are less. The angle gamma has to be considered always.

(3) The *angle gamma* can be measured by making the eye look at the figure which brings the reflection precisely into the center of the cornea.

(4) The degree of *eccentric fixation* (or the position of the "false macula" of some authors) is measured by subtracting the angle gamma of the sound eye from the apparent angle gamma of the squinting one.

(5) *Imperfect abduction* of the squinting eye can also be measured by rotating the head.

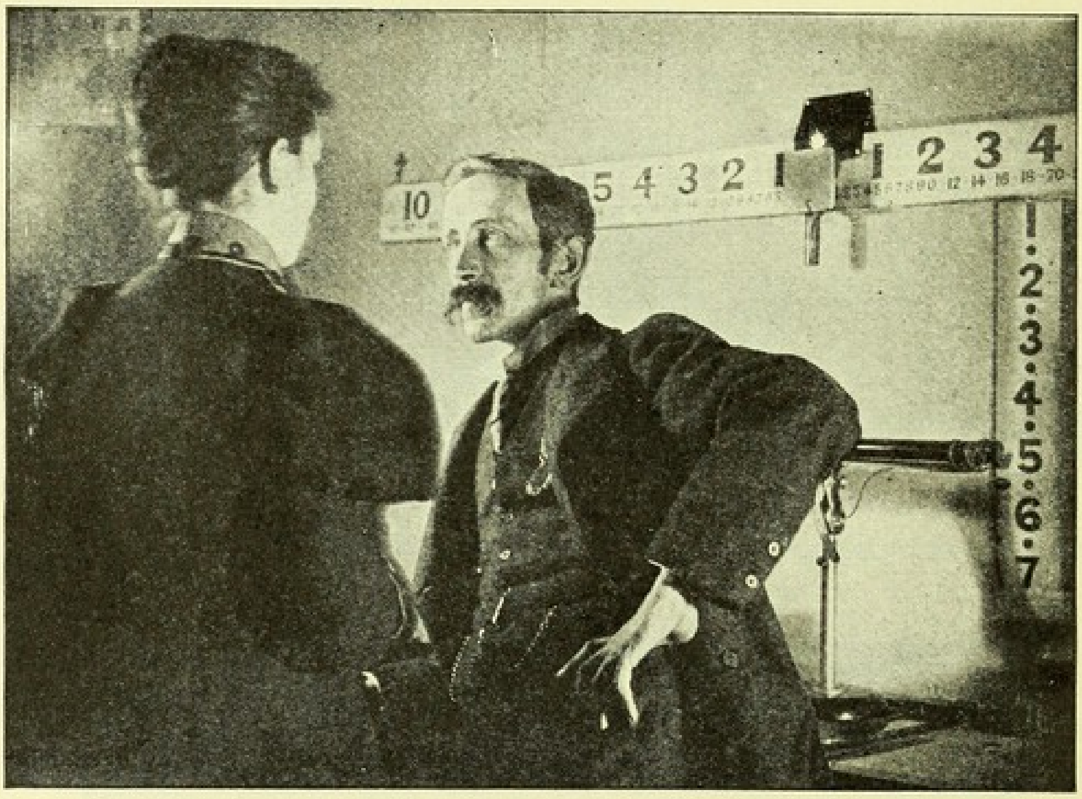


**Fig. 51**

Second step ; examining the refraction. Also estimating the vertical element.

(6) The *accommodative element* can be eliminated by holding the correcting lenses before the fixing eye. Or its increase can be tested by holding a minus lens similarly.

(7) Any *vertical elements* in the squint can be measured by temporary adjustment of a vertical scale, as in Fig. 51, after measuring the horizontal element ; the vertical scale being placed under the figure on the horizontal scale which has been previously settled on, the patient being made now to look at that figure on the vertical scale which brings the reflection to the "fixation-position."*

* Though not necessary in practice, a little calculation would have to be made in scientific inquiries, to correct the variable angles subtended by the figure in the vertical scale in different situations.

The rapidity of measurement by this method favors the good practice of measuring squints before and after operation, which is generally at present dispensed with to save time. Another advantage is that it leaves both hands free to analyze the squint.* The average effect produced by a tenotomy differs, of course, with different operators and in different cases, but about 16° may be reckoned a good effect (Berry). Expressed in linear measure, this would be from 3 to 4 mm.

**Worth's Deviometer.**—This ingenious modification of the above method adapts it admirably to tiny children. An arm, like that of a signpost, on a little stand can be swung so as to point either to the right or to the left and answers to the tangent scale, while a brass carrier can be moved along it, by the tapping of which the child's attention is attracted. An electric light, elongated vertically, at the top of the stand is governed by a small bell-push to enable it to be flashed on instantaneously and off again before the child has time to look at it. The instrument is placed on a table with the nurse seated in front of it holding the child on her knees. Passing a ring on to her finger, to which is attached a string 60 centimeters long, from the center of the instrument, she holds the child's head steady. The surgeon, placed behind the upright stand, looks over its center and proceeds as described in the previous section, first of all guessing the amount of squint by directing attention to the electric light and noticing the eccentricity of the corneal image of the squinting eye as compared with its position in the good one. The brass traveler is then moved along to that position which represents the guess, attention being attracted to it by a tap with the finger or a lighted match, and the guess confirmed or rectified as already described in the tangent-scale method.

**Worth's Modification of Snellen's Test.**—For children who have not learned their letters, Snellen's well-known test with colored glasses for ascertaining the presence of binocular vision, is not available, and Worth's "four-dot test" is an excellent substitute. It consists of four translucent disks set in a black background. Each disk is three inches in diameter and of ground glass, the upper one being red, the lower one white and the two intermediate ones green. The patient, armed with Snellen's frame, is placed five or six yards away. If the trial frame be adjusted with a red glass before the

*Claud Worth has added to the little device, of making the light be turned on and off suddenly when using this test for babies.

right eye and a green glass before the left eye, and the patient sees only two dots, *i. e.*, the white and the red, he is using the right eye only. If he sees three dots, *i. e.*, the white and two green, he is using the left eye only. If he sees four dots, *i. e.*, all the four, he has simultaneous perception with both eyes, and fusion. If five dots, however, from the white appearing double, he has simultaneous perception without fusion, or, at least, without fusion when the two images of an object are differently colored. This is the one weak point of the test, for, needless to say, when the white disk is resolved into two they are no longer white, but are tinted—one green and the other red—by the glasses of the trial frame.

**Worth's Treatment of Infantile Squint.**—By far the most important of the recent advances in this subject have been made by Worth, who has shown with what facility squint can be treated under the age of five or six years as compared with their treatment in later life, over which so much, often unavailing, ingenuity and pains have been spent.

(1) *Optical correction* of any refractive error, of course, comes first. After thoroughly atropizing the eyes for some days, he corrects the whole astigmatism and all but .5 D. of the hypermetropia, and continues the mydriatic until the glasses are made, but no longer. So far this is as others do; but he also counts that "no infant is too young to bear glasses should they be required," and advocates sides so short as only just to reach above the ear and with a loop at the end to enable them to be tied on. In the proximity of the loop the sides should be guarded with wool twined round them to protect the ear. The frequently-used thin plate of celluloid or tortoise shell is also commended.

(2) *Occlusion of the Fixing Eye.*—If the vision of the squinting eye be worse than $\frac{6}{36}$, he advocates, like Javal, *continuous* occlusion, but, since he deals with younger children, does not continue so long; at the most, one or two months. He fixes on a gauze pad, secured by bandage or plaster, for a few weeks, followed by cotton-wool packed behind the spectacle lens.*

(3) *Instillation of Atropine into the Fixing Eye Only.*—Though this has been recommended by Priestley Smith and others previously, Worth has done excellent service in enforcing the value of this procedure more distinctly than heretofore and in showing up

*The author, however, prefers, in other than hospital children, gauze-surrounded lenses with ground glass before the fixing eye, and tied on with tape, since this keeps the fixing eye more cool and comfortable. The wire gauze should have a velvet edge.

the undoubtedly worthless plan, practiced by a few, of atropizing both eyes. He prescribes daily morning instillations into the fixing eye, adding the practical procedure of giving the mother a card on which are written the directions and the date of the next visit. "The best results," he adds, "are obtained in children who are not more than four or five years of age. After six years of age, usually not much improvement in vision can be obtained."

(4) *Training the Fusion Sense.*—If under six years of age, this is carried out by Worth by the use of his "amblyoscope," an ingenious departure from Priestley Smith's fusion tubes, possessing the novelty of a mirror in each tube, which facilitates their convergence, while keeping the graphic designs so far apart as to make it easy to illuminate the one seen by the amblyopic eye more brilliantly than the other, by means of two lamps or electric lights placed over against them. "The favorable time for fusion training is between three and five years."

(5) *Operation.*—For cases in which the deviation is not overcome by other means; advancement for moderate deviations, combined with tenotomy in the higher degrees.

As regards *tenotomy* for convergent squint, the plan of choosing the squinting eye for operation is doubtless the best one, since it agrees with the wishes of the patient, who does not understand "conjugation." Yet I have an impression that a slightly-greater effect would be gained by tenotomizing the other.

If an *advancement* be done, it is better performed on the external rectus of the squinting eye, especially if there be any deficient abduction.

In divergent strabismus the most valuable rule to remember is that if, on approaching the finger towards the straight eye, no converging effort is visible in the diverging eye, tenotomy is an entirely useless procedure; its effect will be nil. Advancement is indicated.

In *absolute* divergent strabismus my experience confirms that of Javal, that "there is no fear of producing an exaggerated operative effect." If, after a surgical interference, a little convergence is left for certain directions of fixation, this effect pretty rapidly disappears. "We cannot," he remarks, "count upon a durable cure unless optical means are employed immediately after the operation. A squint is not definitely suppressed unless the subject has acquired the habit of reading binocularly. When we have to do with an adult whose divergent strabismus has become permanent for an extremely long time, even the most successful operation must be followed by the stereoscopic exercises continued several hours a day for months. I shall quote some examples of success," he adds, "up to the age of forty-five years, but the patients say with truth that the remedy is worse than the disease. Even with females I would not advise undertaking such a cure after the age of twenty or twenty-five years. With young girls from fifteen to twenty years, on the contrary, one is generally seconded by a courage and a patience proof against everything, and success is absolutely assured."

As a commentary on the above remarks about the gradual decrease of operative over-effect, the following illustrative account of one of my cases will be of interest:

M. L., school girl; myopia corrected by — .5 D. Left eye deviates outwards when tired. By objective strabismometry left eye diverges 20° (abbreviated thus: — 20° L. Concomitant. Very low angle alpha.

September 5th.—The r. and l. external recti were tenotomized under chloroform, and the r. internal rectus advanced. Examination by the glass rod and tangent scale gave the following results:

| DATE | ON LOOKING TO RIGHT | ON LOOKING STRAIGHTFORWARD | ON LOOKING TO LEFT |
|---|---|---|---|
| September 14th | + 12° | + 10° | + 3° |
| September 15th | + 10° | + 7° | + 0° |
| October 5th . . | + 10° | + 0° | — 3° |
| October 26th . | + 4° | — 2° | — 4° |
| November 8th . | + 4° | — 2° | — 4° |
| February 5th . | + 2° | — 2° | — 2° |

**Subjective Strabismometry.**—The subjective test is made by holding a disk of red glass rods before the squinting eye and reading off that figure on the same scale which appears crossed by the streak of light. A piece of blue or green glass before the working eye improves the effect by making the images more dissimilar in color and more equal in intensity. (See M. L.'s case, above cited.)

*Concomitancy* can be measured by turning the face to one or other side, as before, and comparing the readings.

**Direction of Fixation.**—In both the above tests the patient's face can, if desired, be turned towards the figure he is fixing, so as to gain the advantage of measurement under the usual conditions of vision with the fixing eye looking straight forward.

**Paralytic Equilibrium.**—So far, we have left out of calculation the modifying effect of Tenon's capsule and its adnexa. Let us now take that into account also. Since the eyeball is so nearly spherical and the center of motion so nearly at its geometrical center, we may, with little error, assume that they are quite so and that equal forces have equal moments. This enables us to say that when a single muscle contracts, the tension in its tendon is equal and opposite to the resultant of all the other tensions, of which there are two groups, namely, those in the remaining tendons and those in the orbital fasciae.

When the same muscle, however, is paralyzed, the eyeball is under the influence of two now opposing groups of tensions, those of the fasciae (which tend to keep it in the primary position*) and those of the tendons of the still unparalyzed muscles (which tend to rotate it away from the primary position). The resultant of these two groups is equal and opposite to the tension which existed during health in the paralyzed muscle. As if guided by this resultant, therefore, the eyeball rotates in the opposite direction about the same axis.

It must be remembered that, in paralyses, though the belly of the affected muscle has lost its contractility, it does not lose its elasticity at once and in some pareses does not wholly lose at once even all its physiological tone, so that the new position into which the eye settles is resisted not only by the tension in Tenon's capsule, but also by the remaining elastic tension in the paralyzed muscle.

For this reason paralysis of a muscle only produces a very slight effect at first, while the healthy eye is in the primary position, *i. e.*, so long as voluntary innervations are quiescent.

**Secondary Contracture, or Consecutive Deviation.**—But as time goes on, the lamed eye deviates more and more, owing to the loss of vital resistance in the paralyzed muscle, to which we may perhaps add what physicists call "fatigue of elasticity" in it and in the resisting portions of Tenon's capsule. Thus arises what is generally called "contracture of the antagonist." Mr. Berry believes that there is no real contracture. I am inclined to believe that in the course of years a slight contracture does occur in the opposing muscle or muscles, but as a consequence rather than as a cause of

*Probably in a more divergent position than the primary, as Hanson Grut has shown.

the increase in the paralytic deviation. When the lame muscle becomes stretched and its resistance enfeebled more and more, the others move the eyeball, without their, however, becoming stronger than they were before.

My impression is that the *consecutive deviation* (as I prefer to call it, since this name commits to no theory) will be found great in proportion to—

(1) The absoluteness of the paralysis ;

(2) The long-standing of the paralysis ;

(3) In proportion as the paralytic deviation is supplemented by a pre-existing latent deviation ;

(4) In proportion to the degree of atrophy of the paralyzed muscle from (*a*) Want of innervation, (*b*) Want of use ;

(5) The more yielding Tenon's capsule is, and the more readily it experiences fatigue of elasticity ;

(6) The more the habit of the patient is to turn the eyes away from the side of the paralyzed muscle ;

(7) The more the patient uses the paralyzed eye ;

(8) In the case of paralytic convergent strabismus, the greater the hypermetropia and the more sensitive the converging center ; and *vice versa* in paralytic divergent strabismus.

## CHAPTER VIII

# Ocular Paralyses

In the absence of any *visible squint*, the most evident symptoms of an ocular paralysis, beginning with the more objective, are:

(1) *Vicarious inclination, or unusual pose, of the head;*

(2) *Imperfect movement of an eye;*

(3) *Magnified secondary deviation;*

(4) *Malprojection;* and, under certain conditions,

(5) *Giddiness, and*

(6) *Uncertainty of gait;*

(7) *Diplopia.*

(8) In addition to these it sometimes happens that *asthenopia, headache* and a *strained* feeling of the eyes are caused by the continual efforts required to preserve single vision in the presence of a slight muscular paresis, though care must be taken to exclude other more likely causes of these symptoms.

If really of muscular origin, they cease when the attempt to maintain single vision is given up. A good practical test, therefore, is to keep the suspected eye covered for a sufficient time and note whether so doing causes the disappearance of the symptoms.

Let us now discuss each symptom in detail.

**Symptom No. 1: Vicarious Inclination of the Head.**—The object of posing the head is to avoid the inconvenience of diplopia, so that these two symptoms are alternate.

Whenever the eyes look in a direction which calls for activity in the paralyzed muscle, its inefficiency is manifested by diplopia. To avoid any call upon the muscle, therefore, the patient turns his head so that the eyes may look in the opposite direction to that of the most troublesome diplopia. It was called "vicarious" inclination of the head by Graefe because the neck muscles do the work instead of the paralyzed eye muscle.

Anyone well acquainted with the subject can generally guess the associated pair of muscles of which one is paralyzed, whenever a patient enters the room with a marked inclination of the head. It is quite easy to guess, if it be remembered that the patient's face looks in the direction of the paralytic diplopia.

There are six directions in which the face may look (if we assume that a single muscle only is affected), and each of these six directions is in relation with its own pair of muscles.

Thus, if the face look to the left, one of the two lævoductors is at fault, either the right internal, or the left external, rectus. A face directed down and to the right impeaches the dextral* depressors ; and so on.

But, after all, we should never trust implicitly to the inclination of the head without proceeding to other tests, for it may be misleading. A fallacy is sometimes introduced by the fact that different components of the diplopia are not equally troublesome to different patients. Some find the *torsion* of the false image trouble them disproportionately, and others the *vertical* displacement ; and, since the inclination of the head is merely adopted by the patient to avoid embarrassment, it does not supply mathematical information. Some patients, indeed, have not yet discovered the best inclination, and need to have it pointed out to them. Differences in different patients arise chiefly from various latent conditions of equilibrium (heterophoria), which pre-existed.

This subject may be closed by a chart of the positions of the face as follows :

| IF THE FACE LOOK | THE AFFECTED MUSCLE IS EITHER | WHICH ARE |
|---|---|---|
| To right . . . . . | R. Ext. R. or L. Int. R. . | Dextroductors |
| To left . . . . . . | L. Ext. R. or R. Int. R. . | Lævoductors |
| To right and up . . | R. Sup. R. or L. Inf. O. . | Dextral † elevators |
| To left and up . . . | L. Sup. R. or R. Inf. O. . | Læval elevators |
| To right and down . | R. Inf. R. or L. Sup. O. . | Dextral depressors |
| To left and down . | L. Inf. R. or R. Sup. O. . | Læval depressors |

**Symptom No. 2: Imperfect Movement of an Eye.**—Though this may be due to some obstruction or incease of resistance as by a tumor or pterygium, such are, in practice, too evident to cause any mistake.

* The word "dextral" must be carefully distinguished from "dextroducting." By a "dextral elevator" we do not mean a muscle that elevates and dextroducts, but one that *elevates most* when the eye happens to be dextroducted by another muscle. The left superior oblique, *e. g.*, is a lævoductor and yet a dextral depressor.

† It must not be forgotten that the superductors and subductors are not called *dextral* or *læval* because of turning the eyes to the right and the left, but because their vertical effect is greatest when the eyes are turned to the right or to the left by other muscles.

**Order of Examination.**—It is good order to test first the *comparative* mobility of the two eyes, with the *conjugate* mobility of both together; followed by the examination of the converging power, and ending with the *absolute* mobility of each.

(1) **Comparative Mobility.**—Commencing, then, our examination by testing the *comparative* mobility of the eyes, we make the patient, with both eyes, follow the point of a finger as it is moved upwards, to right and to left, and intermediate directions. During these manœuvres we watch both eyes closely to see whether they move equally in every direction, or whether one eye tends to linger or "lag" behind the other; and if so, in which direction the lagging is most apparent: this direction will invariably be found to agree with the direction of greatest diplopia.*

(2) **Conjugate Mobility.**—It may be, however, that both eyes are equally mobile and concomitant and yet are equally defective in their movements in one or more directions; this is spoken of as a defect in their "conjugate mobility." For instance, on attempting to follow the finger in its upward path, the two eyes may manifest a perfectly symmetrical inability to rise to the usual elevation. A distinctly less common condition is for them both to fail in their movements to the right or to the left. A little practice is required to learn the normal limits of movements, in order to decide whether a defect of this kind is sufficiently pronounced to be considered pathological, especially as a good deal depends on the amount of effort made by the patient.

*Nystagmus* should be carefully watched for at the limits of the motor field; also during the passage of the finger from one place to another any jerky or irregular movements of the eyes should receive attention.

(3) **Near Point of Convergence.**—The object of the fourth manœuvre, namely, passing the finger nail towards the root of the nose, is to estimate the power of "convergence." Here, again, a little practice with normal eyes is all that is required to learn the average converging power, though the result will be found to depend a good deal on the effort made, and the concentration of the attention. Even when testing a patient who has divergent squint, the estimation of converging power should not be omitted, for though it is only possible for one eye at a time to fix the finger,

*It is, at the same time, well to notice whether the lagging eye manifests any "torsion" in its ineffectual effort to follow the sound eye up or down, for, if it does, the integrity of the oblique muscle which causes the torsion can be taken as proved.

an inward movement observed in the other eye as the finger approaches the root of the nose affords a valuable indication that the faculty of convergence has not been lost, though perhaps for long unused. It is well known that without such converging power, tenotomy of the external rectus will have practically no effect; but with a fair amount of it remaining, tenotomy may be undertaken with more or less prospect of success. Should greater exactness be required, either Landolt's well-known dynamometer can be used, or simply a vertical line on the back of a visiting card, approached to the patient's eyes till he can no longer by any effort keep it from parting into two. The shortest distance from his eyes, measured by a dioptric tape, at which he can still see single, gives the number of meter angles of positive convergence.

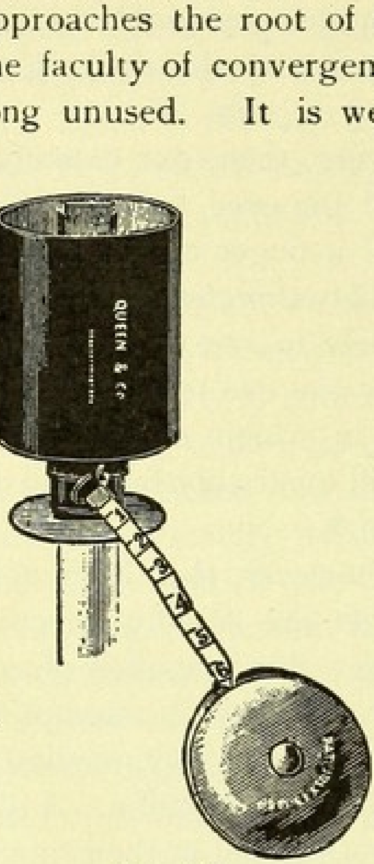


**Fig. 52**
**Landolt's Dynamometer for estimating the near point of convergence**

(4) **Absolute Mobility of Each Eye.**—We may next find the greatest possible excursion of which each eye is capable, while covering the other, by invoking the patient's highest voluntary effort to follow an object to the extreme limits of the motor field in all directions. The value of the test is impaired by the fact that voluntary effort is such a variable quantity, and the palpebral aperture by which we judge the extent of movement is liable to such variations of size and shape in different individuals. In comparing the excursions of the two eyes, however, these disadvantages are reduced to their minimum.

Under normal conditions it is easy to make the outer margin of the cornea touch the outer canthus by strong abduction of the eye, while in full adduction the inner margin of the cornea should be slightly buried beneath the caruncle.

Alfred Graefe's rule is that the inner margin of a moderately-dilated pupil should be brought to touch an imaginary vertical line ascending from the lower "punctum lachrymale."

While inciting these extreme movements, watch again carefully for any appearance of *nystagmus*, and if it should seem desirable to repeat the test with more approach to accuracy, adopt *Landolt's method* with the perimeter. Place the patient's head so that the eye under examination shall lie in the center of the arc of the perimeter ; fix the head, and pass a small piece of diamond type along the arc of the perimeter till the patient ceases by any rotation of the eye to be able to read it. If the eye be amblyopic, it will be necessary to conduct the test objectively, which can be done by passing a small lighted candle along the arc of the perimeter till its reflection occupies the "fixation position" on the cornea, while the patient strives his utmost to look to that side. Schweigger's hand perimeter (Fig. 53) would be the most convenient for this purpose were it provided with a strip of wood for the patient to grip with his teeth.

By either of these methods the motor field can be plotted out for each eye. Its limits are a little greater when tested objectively than when tested subjectively. An excellent suggestion by Casey Wood is to fix a strip of paper with a row of letters on it to the perimeter, and let the patient read along the row till he can read no longer.

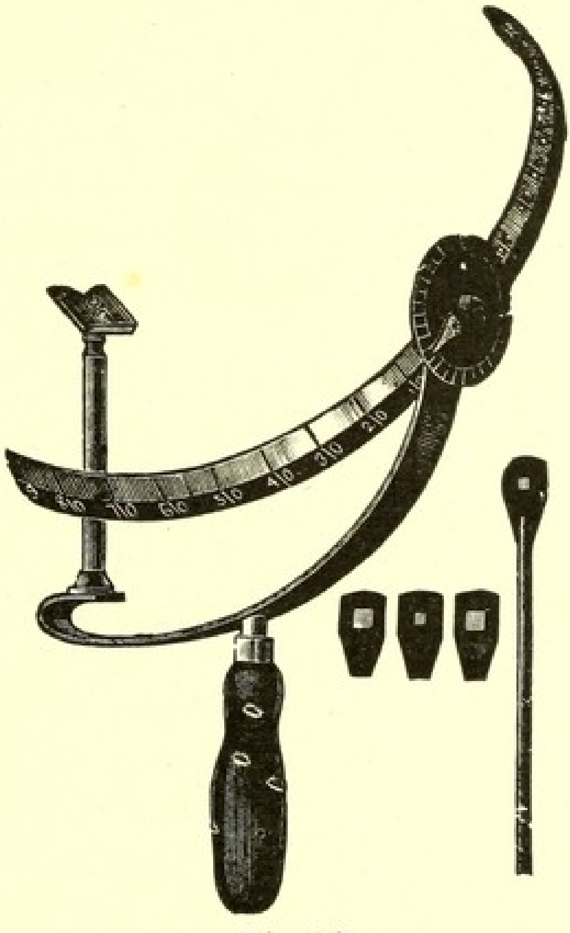

Fig. 53
Schweigger's Hand Perimeter

**Symptom No. 3: Disproportionate Secondary Deviation.**— The "*primary*" deviation is that which is found in the paralyzed eye during fixation of the good, or, as it has been called, the "working" eye. It occurs spontaneously whenever the eyes look in the direction of diplopia.

The "*secondary*" deviation is an artificial phenomenon produced by screening the good eye, so as to compel the paralyzed one to take up fixation as well as it can. The effort required to make the paralyzed muscle contract is out of all proportion to the result, and since half the effort *must* go to the other eye, its deviation becomes greatly exaggerated ; this is then called the secondary deviation.

When the primary deviation, in a slight paresis, is too small to be discerned, the secondary deviation may enable a diagnosis to be made, but to obtain its full effect the eyes must be made to look as far as they can in the direction which makes the greatest demand on the suspected muscle.

Since it is not easy to see the behavior of the good eye behind a cover, *Javal* ingeniously introduced a ground-glass screen, of a circular shape, and which is now to be found in most trial cases as a companion to the colored disks.

This is intended to be held *as close as possible* to the good eye, while the paralyzed one is made to follow the surgeon's finger in the direction of greatest demand on the muscle. The patient's eye can be seen through the ground glass, though he cannot himself see through it, and the secondary deviation can be quietly observed.

Practically, however, the obscured disk is rarely used, because a more accurate idea of the deviation is obtained by suddenly withdrawing the hand, or some quite opaque screen, and observing, first, the amount of deviation ; and, secondly, the extent of the visible corrective movement which the eye makes to reclaim its fixation.

When the affected eye has the best vision or the most useful refraction, the patient will sometimes still use it as the working eye, and then the sound eye deviates. These cases are exceptions to the statement that the secondary deviation is artificially created, for the patient goes about exhibiting it.

**Symptom No. 4: Malprojection.**—This never occurs except when the affected eye is at work, either alone or in company with the other eye. If alone, the malprojection is just twice as great as when fixation is binocular. The principles on which this phenomenon are based have been gone into so fully in earlier pages that little need be added here.

*For Horizontal Ductors.*—The usual plan of testing is to make the patient cover the good eye with a hand, and then suddenly dart his right-hand forefinger at the surgeon's finger held upright, at an arm's length distance from the patient, in such a position as to make a demand upon the paralyzed muscle.

The stab must not be a slow cautious one, neither must the patient aim with his finger before making it. He will miss the mark to the side of the implicated muscle : thus, if the muscle be the right external rectus, he will judge the surgeon's finger to be more to the right than it really is and will miss it to the right, really stabbing at a phantom, namely, the false image, the reason being that the mind estimates by the nervous effort expended on the muscle, as if the muscle were responding to it.

I have nothing to add to the usual mode of performing the test, unless that after the patient has learned to correct for his mistake, which he often does after a few stabs, it is interesting to uncover the good eye and cover the bad to see if he now at first misses the mark to the other side. A few attempts with each eye *alternately* thus, makes the test a more reliable one.

*For Vertical Ductors.*—When the affected muscle is super- or subductor, the projection test is equally simple to make. The surgeon should hold his finger *horizontally* above the horizontal plane, if the muscle be a superductor ; in which case the patient will aim too high, or below it if the muscle be an elevator, when the patient will aim too low.

**Symptoms Nos. 5 and 6: Giddiness and Uncertain Gait.**—The relation of these symptoms to each other and to the last is obvious. They occur only when demand is make upon the paralyzed muscle. Since, in the case of the ocular muscles, the muscular sense is central and not peripheral, it miscalculates when a muscle does not truly respond to its stimulus. It is when depressor muscles are affected that the inconvenience reaches its maximum, since they are needed both for walk and for work. This is seen frequently in the not uncommon paralyses of the superior oblique. Covering the affected eye stops it at once, and sometimes a prism, base down before the weakened eye, and another, base up, before the good eye, will earn the hearty thanks of the patient. Their strength can be selected after an examination by the glass-rod test, and the vertical scale (described in Chapter XII).

**Symptom No. 7: Diplopia.**—This is nearly always the first symptom of which a patient becomes conscious. At the earliest, it is, in most cases, only noticed occasionally ; and may quite disappear for days or weeks, to return again in a more marked form. Later it becomes sufficiently established to appear invariably whenever the eyes are turned in some particular direction. In other cases it commences suddenly and continues.

Diplopia is, of course, absent when one eye is nearly blind, and even when each eye has good visual acuity may be difficult to realize after a paralysis has lasted some years.

There are, however, extraordinary differences among patients in the persistence of the diplopia, some learning to ignore the false image in a few months, while others never succeed in so doing. It is most evident when a bright light is looked at in a dark room, and I find that a piece of black velvet placed behind a source of light so greatly enhances its apparent brilliancy as to aid diplopia.

**Elicitable.**—To elicit diplopia when the patient does not spontaneously perceive it (*a*) We make the true image appear different from the false by placing a *colored glass* before the good eye. (*b*) Another plan is to place a *prism* before the affected eye so as to throw the image on an unusual part of the retina. (*c*) When both of these fail, the *glass-rod* test with a differently-colored disk before the other eye, will nearly always succeed in eliciting diplopia.*

**Monocular Diplopia.**—In practice we rely chiefly upon the nature of the diplopia for the diagnosis of the affected muscle. The first step is to make sure that the diplopia is not *monocular*, by covering each eye in turn to see whether one image disappears in each case. The image which disappears belongs, of course, to the affected eye.

That this precaution is not a needless one may be shown by the fact that I have seen a case of monocular diplopia deceive one of the best of surgeons. The case was, however, peculiarly deceptive in that the diplopia was noticed by the patient only on looking to one side. By the employment of ophthalmoscopic corneal images afterwards I found that there was no deviation of either eye, in any direction of vision, and monocular diplopia was thereupon searched for and found.

**Common but Incorrect Aphorism.**—The statement, so often made, that the affected muscle is the one which physiologically turns the eye in the direction of greatest diplopia, is not strictly correct. Take the superior rectus, for instance: its greatest diplopia when paralyzed is up and out; whereas, its physiological action is to turn the eye up and in.

**Corrected.**—If we qualify the statement by saying that "the lame muscle is one which in health turns the eye in the *cardinal direction* of the diplopia," it becomes at once unfailingly true. The cardinal directions are up, down, right and left. Diplopia,

*I generally find it best to place the glass rod before the good eye, with or without a green glass before the other, the source of light being brilliant, and backed by a velvet screen.

greatest in the upper half of the field, is undoubtedly due to one or more of the elevators ; in the lower half to one of the depressors : in the right half to one of the dextroductors ; and in the left half to one of the lævoductors.* There can be no mistake here, if mechanical obstructions are excluded ; but this aphorism only helps us to find the group to which the affected muscle belongs.

**Second Aphorism.**—Since every paralytic deviation makes the false image travel faithfully in the opposite direction to the eye by an equal angle, and since also the physiological displacement of the eye by the muscle before the paralysis was in precisely the opposite direction to its paralytic deviation, it follows that the false image is displaced exactly as the healthy muscle originally displaced the eye.

To speak figuratively, *when the muscle fails to move the eye, it moves the false image instead* in the same direction that it would have moved the eye. As it *moves* the image in disease, it *moved* the eye in health.

This makes it very easy to detect the muscle. Is, for example, the false image (relatively to the true) elevated, adducted and intorted? Then the muscle must be an elevator, adductor and intortor. Only one muscle in each eye is this, namely, the superior rectus ; so the case is solved.

**Complications.**—If there were no complications, this "second aphorism" would suffice for all our need. But only a part of the displacement of the false image may be due to the paralysis, the remainder being the result of latent squint (heterophoria) which may have pre-existed for years, though now set free by the paralysis. This introduces a fallacious element and requires that we should so make our tests as to avoid it.

Again, more than one muscle may be affected, and we might, if unwary, be caught in a trap.

It is better, therefore, to reserve the "second aphorism" to the end of our investigation and use it only for confirmation. Even then, to get the full benefit of it, account must be taken of the direction in which the sound eye is looking, for muscles have different effects in different positions of the eyeball, and the position in which the muscle is most valuable is that in which its loss is most felt, and the paralytic diplopia, therefore, is greatest. The superior rectus, for instance, is a more efficient elevator when the eye is

* The convenience of these terms will at once be perceived

abducted to start with ; therefore, in abduction, its vertical diplopia from paralysis is greatest. In adduction it is a more efficient intortor ; therefore, in this position of the eye, its torsional diplopia from paralysis is most marked. And so on.

**Clinical Procedure.**—For clinical work we must employ the method which, while thoroughly simple, is freest from pitfalls.

Instead, therefore, of merely considering the one displacement of the false image, we should investigate separately its vertical, horizontal and torsional components, giving to each its relative value, since they are not equally trustworthy for diagnosis. We have to *weigh* the evidence, and not merely count it.

**Narrowing Circles.**—Instead of rushing straight for our muscle, we reach it by stages, just as a botanist with a flower enquires successively into its natural order, its genus and its species.

(*a*) *Cardinal Groups.*—We begin by finding to which of the four *cardinal groups* the muscle belongs, whether that of the elevators, the depressors, the dextroductors, or the lævoductors, in which group a paralysis makes the diplopia increase respectively upwards, downwards, to right or to left. If two or more groups seem affected, begin with the worst, not forgetting that vertical diplopia is relatively more important than horizontal diplopia, since the latter, if it extended all across the field, may be due to some anomaly of the converging center.

The most convenient test object is the ever-ready white handle of an ophthalmoscope, and it is quite enough in simple cases. If, however, the false image be faint, or the patient unobservant, a colored glass before the sound eye may be necessary, used in conjunction either with a lighted candle, or a strip of white paper mounted on black velvet,* to obtain a contrast effect.

Place the patient with his back to the window, and charging him to hold his head erect and follow the test object with his eyes, move it upwards, downwards, to right and to left, over the surface of an imaginary hemisphere, of which his head is the center and with a radius of about a meter.

While testing the horizontal motions of the eyes, hold the handle of the ophthalmoscope vertically, but in testing above and below, hold it horizontally, since in these positions the vertical component

* The ideal test object would be a luminous glass rod about six inches long and mounted against black velvet.

of the diplopia is the most important and it is more readily estimated by a horizontal than by a vertical test object. If the diplopia is found only on looking upwards, there is some defect among the group of sursumductors ; if on looking downwards, among the group of deorsumductors ; if to the right, among the group of dextroductors ; and if to the left, among the group of lævoductors.

(*b*) **Affected Eye.**—Having found the *group*, the next thing is to find the *eye*, which is easily done, while the test object is still held in the area of maximum diplopia, by rapidly screening one eye two or three times in succession with the hand, in order to find which image belongs to the screened eye. It is, of course, the image which disappears and reappears.

*The image which lies farthest in the direction of increasing diplopia belongs to the paralyzed eye.*

If the affected muscle be an internal or external rectus, our work is done when we have found the *group* and the *eye*, for each eye has only one dextroductor and one lævoductor.

(*c*) **Delinqueut Vertical Ductor.**—But if the fault be among the group of elevators or depressors, one more step is needful, since each eye has a pair of each, of which one is ever a rectus and the other an oblique.

The next thing to do is, while holding the test object (itself horizontal) in the diplopic half of the field to pass it first to the right hand and then to the left, to note in which position the vertical component of the diplopia appears greatest to the patient. If, on looking to the same side as the *paralyzed* eye, the difference in height is greater than on looking to the other side, the affected muscle is a *rectus*. If the difference in height is greatest on looking to the side of the *sound* eye, the affected muscle is an *oblique*.

If we do not know which eye is wrong, we may still decide in the same way, whether the affected muscle is dextral or læval in its action.*

**Dextral and Laeval.**—It is very easy to recall which muscles are dextral and their vertical effect, and which læval, since the dextral are those whose tendons point to the right, and the læval

* The reader who is accustomed to speak only of lateral and medial elevators, and adduction and abduction, may possibly challenge the change to dextral and læval, dextroduction and lævoduction. The reason for it is that since the former terms refer to the median plane, students and beginners make *frequent* mistakes when the test object lies to the opposite side of the median plane from the affected eye, calling an adducted image an abducted, and so on. This constant liability to error is entirely removed by the change of terms I have employed. It would not have been made otherwise. But this is not all : the change of terms enables us to adhere more closely to nature, for dextroducting and lævoducting innervations exist, but we have no certain knowledge of an abducting innervation.

those which point to the left. Fig. 54 makes this very clear and is easily borne in mind after a few moments' contemplation of it, the tendons of the obliques being treated as if they pointed forwards and inwards, instead of backwards and outwards.

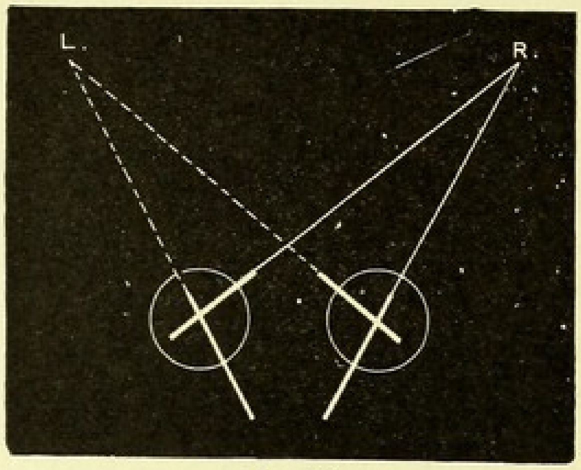


**Fig. 54**

To show how those Muscles whose vertical effect is dextral have their directions pointing to *R.* The Lævals have their directions pointing to *L.*

A moment's consideration will show how it must be that a muscle alters the height of the cornea most when the visual line comes to lie in its muscular plane.

Since a dextral muscle is one whose muscular plane points to the right and a læval muscle one whose muscular plane points to the left, it will be seen that the recti rightly describe themselves, for the *right* recti are *dextral* in their action, and the *left* recti, *læval.*

The obliques are contrary. The dextrals, therefore, are the right recti and the left obliques; the lævals, the left recti and the right obliques.

There is no need, however, to commit anything to memory, since the anatomical disposition of the muscles can always be called to mind sufficiently to recollect whether its line of force points to the right or to the left. The attitude of Fig. 55 may come to the help of any one unable to conjure up the muscles.

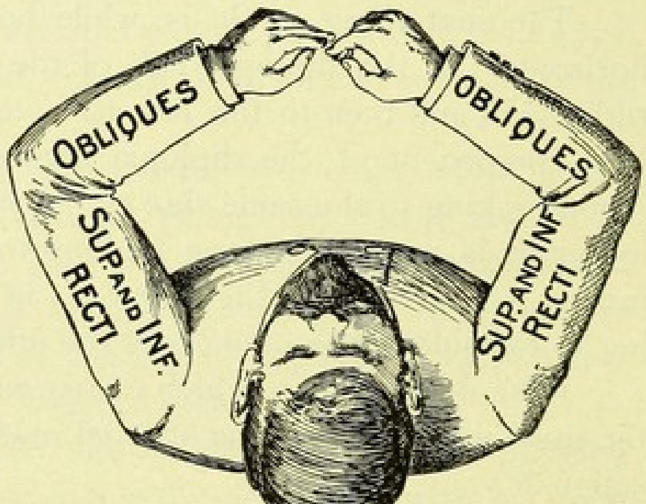


**Fig. 55**

Mnemonic attitude for the Muscular Planes (borrowed in part from Landolt).

**Torsional Purchase and Vertical Purchase Reciprocal.**—While the vertical purchase of a muscle is greater in proportion as its muscular plane is approached by the visual line, its torsional effect, on the contrary, increases as its muscular plane is departed from by the visual line. Thus, the figure shows that when the eyes look to the right the dextrals have the greatest elevating or depressing effect, and the lævals have the greatest torsional effect; and *vice versa* on looking to the left.

The corollary is that the greatest torsion of the false image is always to be found on the opposite side of the median plane from its greatest vertical displacement, *i. e.*, if the greatest vertical separation is up and to the *right*, the greatest torsional displacement will be up and to the *left;* or if one is down and to the right. the other will be down and to the left.

As soon as we have settled whether the muscle is dextral or læval, our task is done, and the diagnosis made.

**Recapitulation.**—To summarize, we find*:

(1) Which group { Elevators? Depressors? Dextroductors? Lævoductors?

(2) Which eye? The eye which sees the most advanced image in the direction of diplopia.

(3) Rectus or oblique? *Rectus*—if the maximum vertical diplopia be on the side of the paralyzed eye. *Oblique*—if on the side of the sound eye.

**Confirmation of the Diagnosis.**—It is well, if time allow, to study the three components of the diplopia in different parts of the field.

While we do not trust much to the torsion, or to the minor degrees of horizontal diplopia, in *discovering* the muscles, they both, but especially the former, afford valuable *confirmation;* and if the torsion conflicts with our discovery, the initial investigation should be repeated.

The best plan for confirmation is to draw up a motor chart in the usual way, dividing the field into nine areas, as shown in Fig. 57, and carefully representing the false image over as many as it appears in.

The non-diplopic areas constitute the "field of single vision," and this can, if desired, be also filled in by the aid of the glass rod, though hitherto the field of single vision has been generally left unanalyzed.

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* Personally, I prefer to find the eye last, but have adhered to the usual order in the text as being more easily explained.

**Measured Charts.**—If more accuracy be required, the three components of the diplopia (vertical, horizontal and torsional) can be *measured* in degrees for each area by the glass rod and the tangent scales.

**Construct, then Scrutinize.**—It is well to fill in the entire chart before reasoning on it, so as to be unprejudiced in the observations. Then, see if the false image corresponds in each area to the physiological action of the suspected paralyzed muscle during vision directed towards that area For this we recur to the italicized rule previously enunciated. Another way of putting it, more handy than elegant, is--"What the muscle *does;* the false image *is.*"

**Example.**—For example, suppose the left inferior oblique to be implicated. We know that it becomes a purer and stronger sursumductor on looking to the right (Fig. 54). The false image, therefore, in the right upper part of the field will be more purely and greatly sursumducted above the true, than anywhere else (Fig. 68).

We know, too, that it still has *some* lævo-torsional purchase, even on looking to the right, and that it still slightly lævoducts the left eye; therefore, the false image will be lævotorted and slightly lævoducted. accordingly, in that same area.

We know, further, that on looking to the left the elevating power of the left obliques almost ceases, and their torsional and abducting effects reach their maximum; therefore, in the left upper area of the field the false image will be but slightly higher than the true, though greatly lævotorted and moderately lævoducted. In the lower part of the motor field the muscle has but trifling sway, and, therefore, here diplopia disappears, the false image running into the true.

**Names of the Areas.**—In drawing up the chart, let everything be denominated by the *patient's* right and left, and not by the surgeon's. This is an invariable rule for everything in ophthalmology. Fig. 74, which will appear in its numerical order, shows the names which I think it best to permanently give to the areas, in view of a namesake principle to be described later on. They are names easily recalled, because simply descriptive of their position from the patient's point of view.

**Inscription.**—The mode of inscribing the false image or the diplopia is a matter of taste, and I have not yet settled on a final choice. My favorite way at present is to represent the true image by a dot in the center of each area, leaving the imagination to construct a vertical line through the dot. Then a thin vertical line from the dot represents the vertical element, a horizontal line from the end of that the horizontal element, and a larger dot at the end of that line represents the false image.

The advantage of this plan is that we are not bound to inscribe the torsion if the patient's account of it is unsatisfactory, while if we do wish to inscribe it, a thin line through the second dot shows it at once (as in Fig. 56). Moreover, if we wish to make a quantitative record, we can use dotted lines and make each dot represent a degree, to represent the horizontal and vertical element; or an inch, or any unit we like to choose. The torsion can also be marked in degrees.

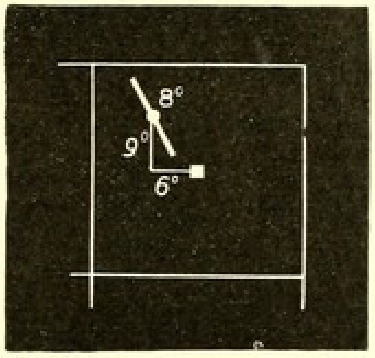

Fig. 56

**Never forget** to record on the chart to which eye the false image belongs.

**Even Incorrect Statements are Valuable, if True Comparatively.**—It need hardly be said that comparative statements about the diplopia in the different areas are more common with patients than absolutely true measurements, yet though the patient's idea of an inch may be far out, it does not matter if he is consistent otherwise, and maintains his peculiar inch throughout. To enable him to do so, care should be taken to hold the test object at the same distance from the eyes throughout the test. With the ophthalmoscope handle, three or four feet is a convenient distance; with a candle, six feet.

If more than one muscle be affected, the diplopia may increase in more than one direction, and each direction may then be studied independently. Thus, if a depressor and an elevator be both paralyzed, diplopia will increase both upwards and downwards, and become almost nil on looking straight forward.

In dealing with multiple paralyses, a careful inscription should be made in every area of the chart, without bias or prejudice, and then the affected muscles should be puzzled out from it.

**To Read a Simple Chart.**—At the risk of being tedious, I will give one example of a single paralysis. An inspection of Fig. 61:

(*a*) Shows diplopia *upwards;* therefore, involving one of the group of sursumductors.

(*b*) The highest image (say) belongs to the right eye; therefore, the muscle is one of the elevators *of the right eye.*

(*c*) Its maximum vertical diplopia is up and to the right; therefore, it is a *dextral* superductor. But there is only one such muscle of the right eye—the superior rectus. Found, therefore.

Does the torsion agree? Yes; for though there is none in the right superior area, there is marked lævotorsion in the left superior. Had it been a case of the right inferior oblique, the greatest elevation would have been to the left side, and the greatest torsion to the right side; moreover, the torsion would have been dextrotorsion. The diagnosis is confirmed, therefore.

**To Read a Multiple Chart.**—(*a*) Begin by noticing in how many and which cardinal directions the diplopia seems to increase, and if it does so in more than one direction, begin with that of *greatest* diplopia. Observe which *group* this greatest diplopia points to. (*b*) If the observed diplopia be horizontal, the muscle is found, for the image most removed from the center of the chart belongs to the affected eye. (*c*) If the diplopia be vertical, the muscle affected is a rectus, if the area of greatest vertical diplopia is on the same side as the eye that sees the false image: it is an oblique if on the opposite side.

Next find the direction of second greatest (independent) diplopia and study that in the same way. Then the third, and so on.

**Independent Diplopiae.**—Diplopiæ in opposite halves of the motor field in which the false image occupies opposite sides of the true image are independent.

If the false image remain on the same side as the true all across the field, then it is not a case of two independent diplopiæ, but there is a concomitant element, due either to an anomaly of the converging innervation or to what is generally called the "secondary contracture."*

If the separation of the images is constant in amount, the diplopia is entirely concomitant; but if it differs in degree in different areas while ever the same in kind, there is a paralytic element as well as a concomitant one.

Concomitant elements are distinguished by pervading the whole field and, therefore, an investigation of every area in the field of single vision, as by the rod test, leads to a fair estimate of their amount.

In all multiple paralyses the diplopia produced by one muscle may alter that due to another, so that any untypical features of

*The concomitancy of "secondary contracture," or "consecutive deviation," as it is better to call it, is very imperfect, the deviation becoming less and less towards the limits of minimum diplopia.

diplopia should be examined to see whence the disturbance from the typical proceeds, just as an astronomer discovers planets unknown to him by observing the disturbances of those he does know. Those who have not experienced it are little aware of the difficulties that sometimes attend the analysis of multiple paralysis, with much heterophoria.

**Guides.**—With regard to the *direction of greatest diplopia*, it is useful to bear in mind the following three guides to it, which, however, are only roughly true :

(1) The *face* looks at it.

(2) The affected *eye* lags from it.

(3) The *false image* travels towards it.

The following chart classifies the twelve ocular muscles, not anatomically but physiologically, and as we have to study them clinically :

| | | |
|---|---|---|
| 4 *Sursumductors* | 2 Dextral | R. Sup. Rectus.<br>L. Inf. Oblique. |
| | 2 Læval | L. Sup. Rectus.<br>R. Inf. Oblique. |
| 4 *Deorsumductors* | 2 Dextral | R. Inf. Rectus.<br>L. Sup. Oblique. |
| | 2 Læval | L. Inf. Rectus.<br>R. Sup. Oblique. |
| 2 *Dextroductors* . . . . . . . . | | R. Ext. Rectus.<br>L. Int. Rectus. |
| 2 *Lævoductors* . . . . . . . . . | | L. Ext. Rectus.<br>R. Int. Rectus. |

It will be seen that the six pairs in the right-hand column are Graefe's "*true associates.*"

# CHAPTER IX

## Ocular Paralyses (*Continued*)

**Optical Illusion.**—Patients sometimes mention that the lower of the two images, which are seen when any depressor muscle is paralyzed, appears nearer to them than the true image. As bearing on this, Nagel has shown that a ball hanging on a thread, presented to the inspection of a person with vertical diplopia, appears as two balls, one vertically above the other ; while the same ball on a plate appears as two balls (and of course two plates), one in front of the other. This clearly indicates the nature of the phenomenon in our patients. They estimate the nearness of the false image with reference to a horizontal plane, generally the *floor*, which corresponds to Nagel's plate, instead of estimating it with reference to a vertical plane, such as the *wall*, which would answer to his thread. A line proceeding from the eye through the lower image would, of course, strike the floor at a nearer point than a similar line through the higher image.

The illusion can, therefore, be dissipated by any plan which occupies the patient with the wall to the exclusion of the floor ; as, for instance, by placing the candle or test object against the wall at a sufficient height while the patient's head is thrown back a little (Landolt).

If the false image also appear smaller than the other, it is probably only because it is thought to be nearer.

**How to Transfer Charts to Opposite Eyes.**—It is usual in text-books to give the charts of ocular paralyses for one eye only, since it is supposed to be so easy for the reader to mentally transfer each feature of the chart from right to left, or *vice versa*. And truly, it is easy ; but for anyone in haste, or not accustomed to the subject, to make a mistake in so doing, is, perhaps, easier still.

To overcome the difficulty in the case of beginners, I would propose one of the following simple expedients, any one of which will suffice :

(1) Prick the chart through to the back of the page ; this affords the required transference. *Or*,

(2) Hold the chart before a looking-glass, its image in which affords what is needed. *Or*,

(3) Imagine the chart, by closing and reopening the book, to have become transferred to the opposite page; or actually trace the chart over with copying ink and transfer it to a thin sheet of paper gummed into the book. *Or*,

(4) To obtain the chart for any uncharted superior or inferior rectus, turn the chart for the antagonistic rectus in the other eye upside down. For instance, the right superior rectus is charted by inverting the chart for the left inferior rectus. Exactly the same procedure avails also for the obliques. The chart for any superior muscle need only be folded from above downwards, and transferred to give the chart of the corresponding inferior muscle of the same eye. The best plan of all, however, is to possess a chart of every muscle, to save time, and this I have given.

Let us now consider the individual paralyses. It will be noticed to be roughly true that

1. The primary deviation (*i. e.*, that of the paralyzed eye) is *opposite* to the direction in which the healthy muscle turns the eye.

2. The remaining displacements are all in the *same* direction as that in which the healthy muscle turns the eye.

## Paralysis of Right External Rectus

This muscle turns the cornea to the *right*, therefore there result:

1. **Primary Deviation** (of paralyzed eye)—To the patient's *left*.

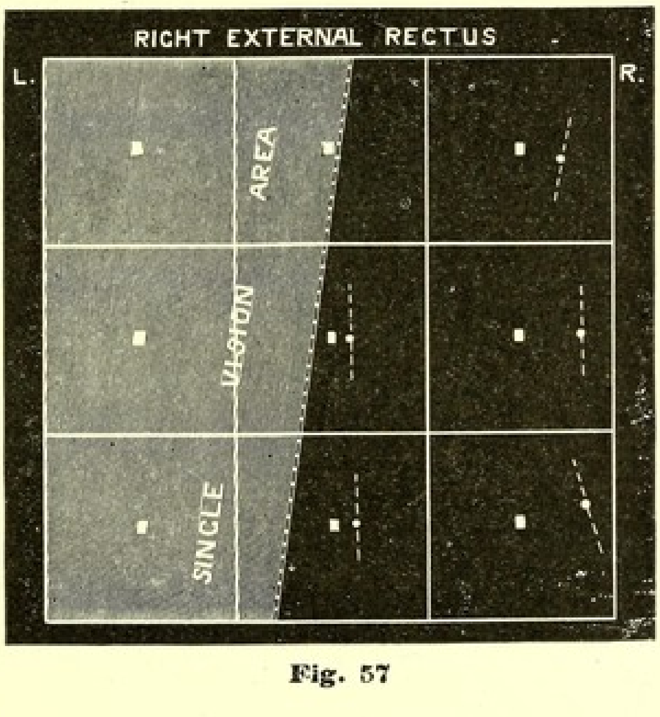


**Fig. 57**

| | |
|---|---|
| 2. **Face looks**<br>**Defect in Motion of Eye**<br>**Secondary Deviation** (*i. e.*, of sound eye)<br>**Malprojection**<br>**Maximum Diplopia**<br>**False Image Displaced** | To the patient's *right.* |

**Diplopia.**—Horizontal, homonymous, increasing on looking to the right, and also with recession of the test object. Greater, too, on looking downwards ; less on looking up.

### Paralysis of Left External Rectus

The muscle turns the cornea to the *left*, therefore there result :

1. **Primary Deviation**—To the patient's *right.*
2. **Everything else**—To the patient's *left.*

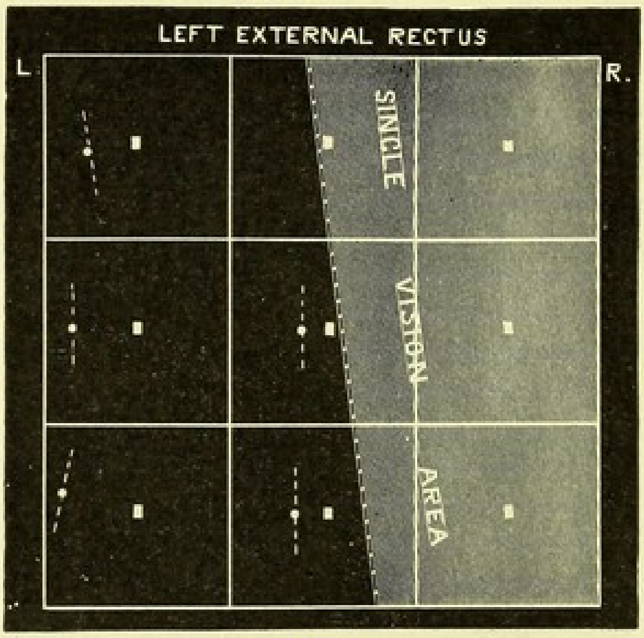


**Fig. 58**

**Diplopia.**—Horizontal, homonymous, increasing on looking to the left, and also with recession of the test object. Greater, too, on looking downwards ; less on looking up.

### Qualifications in Paralysis of the External Recti

Two unimportant refinements, one of which has already been partly indicated, require notice in paralysis of either external rectus.

*First Qualification.*—The horizontal separation of the images is apt to increase on looking downwards, and lessen on looking upwards. This is due to the habit of the converging center, for looking downwards is generally associated with convergence, and looking upwards with parallelism of the visual axes.

*Second Qualification.*—On looking up and out, the inferior oblique of the paralyzed eye; and on looking down and out, the superior oblique, lose their usual torsional purchase on the paralyzed eye, because its visual line keeps nearer their muscular plane. The purchase which they lose torsionally, however, they gain vertically, so that the weak eye is really superducted and subducted slightly more than the sound one, when the latter looks respectively up and out, and down and out.

In consequence of this, the false image, on looking up and out, is *lower* than the true and *extorted*, and on looking down and out is *higher* than the true, and *intorted*. It will be remembered that, under physiological conditions, there is "false torsion" on looking in these directions, but the effect of the paralysis is to abolish it, since it disables the eye from turning out, and false torsion is absent from the simple vertical motions of the eye. Indeed, paralysis of the external rectus affords a beautiful demonstration of the existence in health of false torsion, since the mind, accustomed to reckon for it, projects the false image precisely in its direction. The lack of torsion in the eye causes exaggerated torsion of the image, eye and image being always opposite in their deviations.

Putting these two qualifications together, we find it necessary to slightly modify the preceding statements.

*Primary Deviation.*—Inwards: inwards and slightly upwards in the upper outer parts of the field; inwards and slightly downwards in the lower outer parts.

*Face Looks*—To the right; perhaps also *slightly* upwards.

*Defective Movement.*—To right. More so when the eyes look downward.

| | | |
|---|---|---|
| *Secondary Deviation.* *Malprojection.* *False Image Displaced.* | *In the upper outer parts of the field.* | Outwards and slightly downwards. |
| | *In the lower outer parts of the field.* | Outwards and slightly upwards. |

*Maximum Diplopia.*—On looking down and out.

## Paralysis of Right Internal Rectus

This muscle turns the cornea to the *left*, therefore there result:

1. **Primary Deviation** (of paralyzed eye)—To the patient's *right.*
2. **Face looks**
   **Defect in Motion of Eye**
   **Secondary Deviation** (of sound eye)
   **Malprojection**
   **Maximum Diplopia**
   **False Image Displaced**
   } To the patient's *left.*

**Diplopia.**—Horizontal, crossed, increasing on looking to the left, and also with approach of the test object. Greater, too, on looking up ; less on looking down.

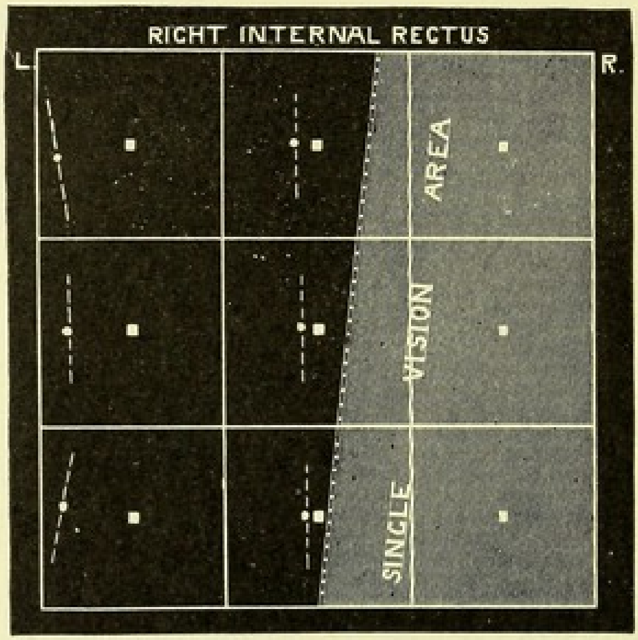


**Fig. 59**

## Paralysis of Left Internal Rectus

This muscle turns the cornea to the *right*, therefore there result :

1. **Primary Deviation**—To the patient's *left*.
2. **Everything else**—To the patient's *right*.

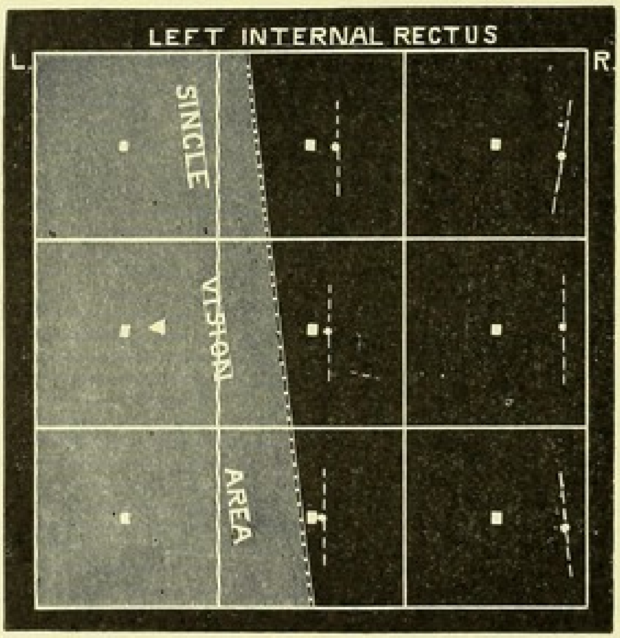


**Fig. 60**

**Diplopia.**—Horizontal, crossed, increasing on looking to the right and also with approach of the test object. Greater, too, on looking up; less on looking down.

## Qualifications in Paralysis of the Internal Recti

Two unimportant refinements (akin to those for the external recti) require notice.

*First Qualification.*—The horizontal separation of the images is apt to increase on looking upwards and lessen on looking downwards, due, as in the case of the external recti (*q. v.*), to the habit of the converging center.

*Second Qualification.*—On looking up and in, the superior rectus of the paralyzed eye; and on looking down and in, the inferior rectus of the same eye, lose torsional purchase over the eye from the fact that their muscular plane forms a smaller angle with its visual axis than when adduction is efficient. Hence, on looking up and in, the false image should theoretically be *lower* than the true and *intorted;* and on looking down and in, it should be *higher* than the true and *extorted.* Absolutely isolated paralysis of the internal recti are, however, so rare that this could scarcely have been discovered from actual experiment. It is chiefly from the analogy of the external recti that it is assumed to occur. It will be seen represented in the charts.

## Paralysis of Right Superior Rectus

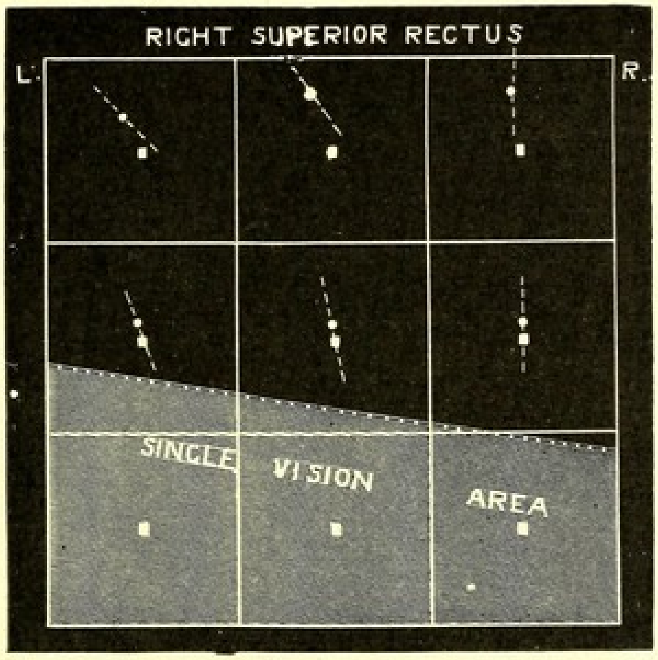


**Fig. 61**

This muscle turns the cornea *upwards*, and somewhat *inwards*, with *intorsion.* Its power as a superductor is greatest during vision to the right. It is, therefore, a "dextral superductor."

Its power, on the other hand, as adductor and intorter is greatest during vision to the left. Therefore, there result from its paralysis :

1. **Primary Deviation** (*i. e.*, of paralyzed eye)—*Downwards;* and, in the upper half of the field, *outwards;* with *extorsion.*

2. **Face looks**—*Up* and to the *right.*

**Defect in Motion of Eye**—*Upwards;* most marked when the eyes are also turned to the right.

**Secondary Deviation**—(*i. e.*, of sound eye)—*Upwards*, and slightly to the left, probably with a little lævotorsion.

**Malprojection**—*Upwards*, and slightly to the left.

**Maximum Diplopia**—On looking *up* and to the *right.*

**False Image Displaced**—*Upwards* and slightly to the left, with lævotorsion.

**Diplopia.**—Vertical diplopia, increasing on looking up, and especially up and to the right ; crossed and torsional diplopia *increasing* on looking up and to the left. The nature of the diplopia during the primary position of the sound eye should be carefully investigated, and the equilibrium should be examined (by the rod test, *e. g.*) in the non-diplopic half of the field. This remark applies equally to all the succeeding paralyses.

## Paralysis of Left Superior Rectus

Same as the last, with substitution of "left" for right, and

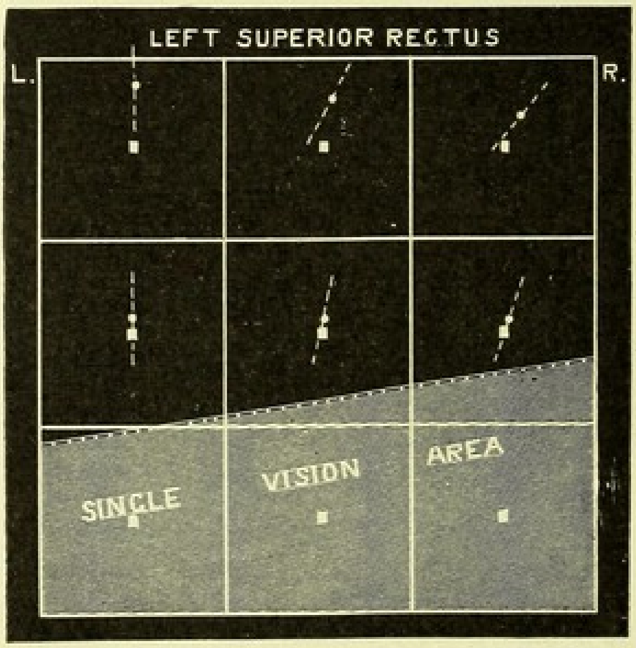


Fig. 62

*vice versa.* It turns the cornea up and in, with inward torsion, and is a læval elevator. (Fig. 62.)

### Paralysis of Right Inferior Rectus

This muscle turns the cornea *downwards* and somewhat *inwards*, with *extorsion.* Its power as a subductor is greatest

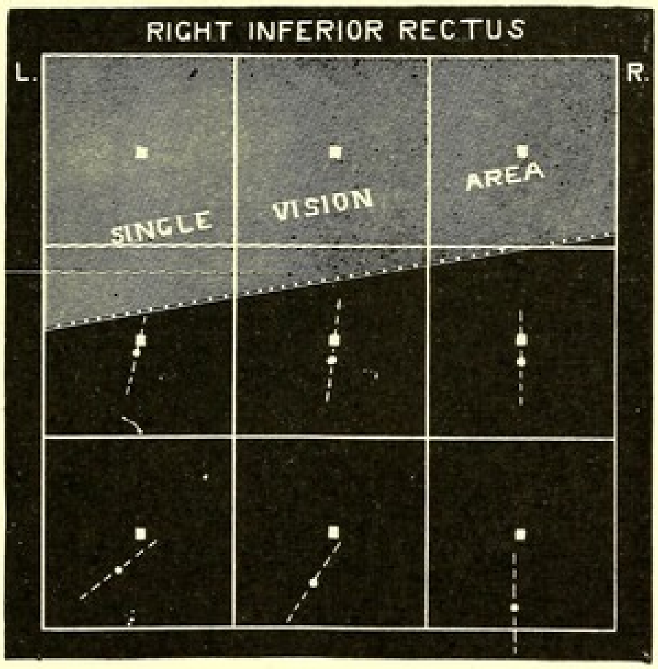


Fig. 63

during vision down and to the right. It is, therefore, a "dextral subductor." Its power, on the other hand, as an adductor and extorter is greatest during vision down and to the left. There result from its paralysis

1. **Primary Deviation** (*i. e.*, of paralyzed eye)—*Upwards* and, in the upper half of the field, *outwards;* with *intorsion.*

2. **Face looks**—*Down* and to the *right.*

**Defect in Motion of Eye**— Downwards, most marked when the eyes are also turned to the right.

**Secondary Deviation** (*i. e.*, of sound eye)—*Downwards*, slightly to left, with dextrotorsion?

**Malprojection**—Downwards, slightly to left.

**Maximum Diplopia**—On looking *down* and to the *right.*

**False Image**—Downwards and slightly to left.

**Diplopia.**—Vertical diplopia, greatest on looking down and to the right; crossed torsional diplopia, greatest on looking down and to the left.

PARALYSIS OF LEFT INFERIOR RECTUS

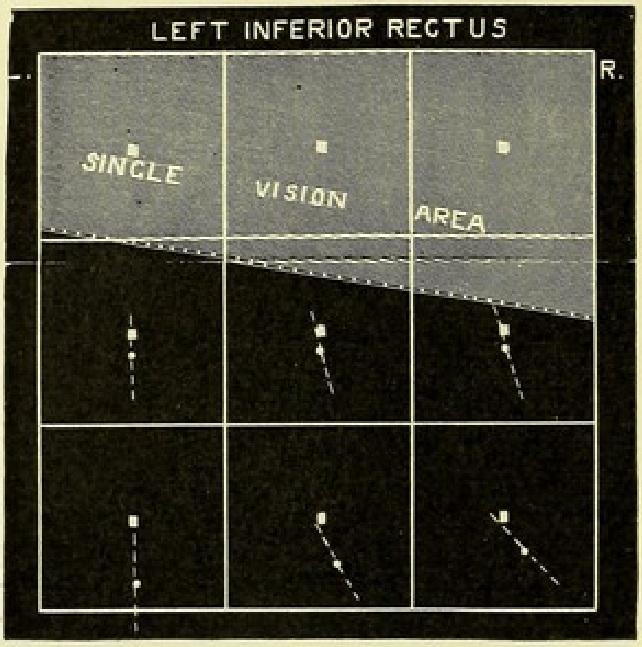


Fig. 64

Same as the last, with the substitution of right for left, and *vice versa* throughout. It turns the cornea *down* and *in*, with *extorsion*, and is a "læval depressor."

PARALYSIS OF RIGHT SUPERIOR OBLIQUE

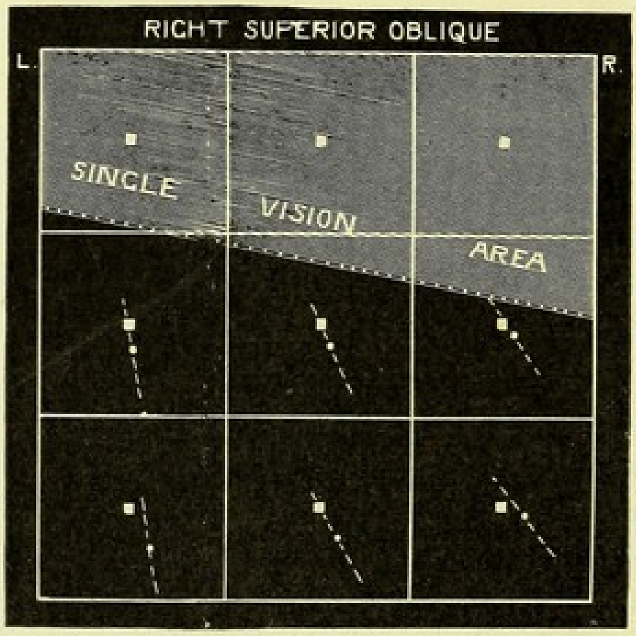


Fig. 65

This muscle turns the cornea *downwards* and *outwards*, with *intorsion*. Its power as a depressor is greatest during vision to the left ; it is, therefore, a "læval depressor." Its power, on the other hand, as an intorter and abductor is greatest during vision to the right, because then its muscular plane forms the greatest angle with the visual axis. There result from its paralysis :

1. **Primary Deviation** (*i. e.*, of paralyzed eye)—*Upwards* and, in the lower half of the field, slightly to the *left ;* with *extorsion.*

2. **Face looks**—*Down* and to the *left.*

**Defective Motion of Eye**—*Downwards*, especially when vision is directed down and to the left.

**Secondary Deviation** (*i. e.*, of sound eye)—*Downwards* and slightly to the right, and lævotorted.

**Malprojection**—*Downwards* and slightly to the right.

**Maximum Diplopia**—*Downwards* and to *left.*

**False Image Displaced**—Downwards, slightly to the right, and lævotorted.

**Diplopia.**—Vertical diplopia, greatest on looking down and to the left ; torsional diplopia greatest on looking down and to the right ; generally homonymous diplopia greatest on looking down and to the right, but sometimes crossed.

## Paralysis of Left Superior Oblique

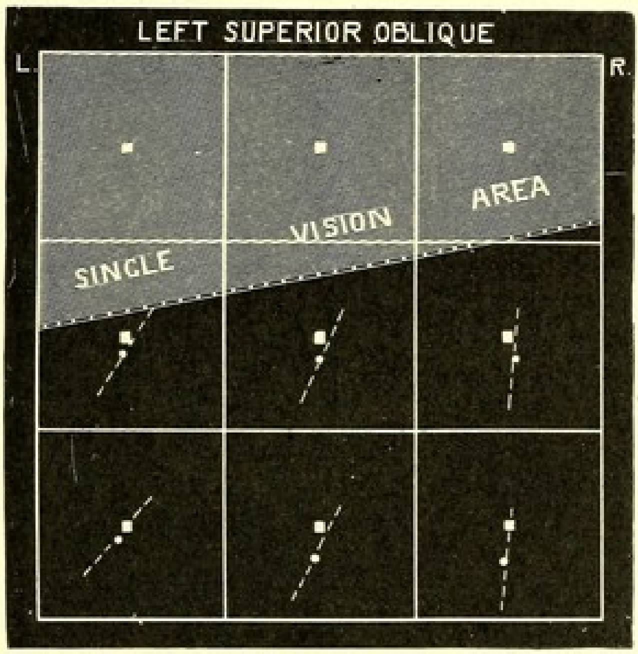


**Fig. 66**

Same as the last, substituting right for left, and *vice versa* throughout. It turns the cornea *down* and *out*, with *intorsion*, and is a "dextral depressor."

### Paralysis of Right Inferior Oblique

This muscle turns the cornea *up* and *out*, with *extorsion*. Its power as a superductor is greatest during vision to the left; it is, therefore, a "læval elevator." As an extorter and abductor, on the other hand, its power is greatest during vision to the right, when its muscular plane forms the greatest angle with the visual line. There result from its paralysis:

1. **Primary Deviation** (of paralyzed eye)—*Downwards* and, in the upper half of the field, *inwards;* with *intorsion*.
2. **Face looks**—*Up* and to the *left*.

**Defect in Motion of Eye**—*Upwards*, especially when vision is also directed to the left.

**Secondary Deviation** (*i. e.*, of sound eye)—*Upwards* and slightly to the right, with dextrotorsion.

**Malprojection**—*Upwards* and generally to the right.

**Maximum Diplopia**—On looking up and to the left.

**False Image Displaced**—*Upwards* and generally to the right, with dextrotorsion always.

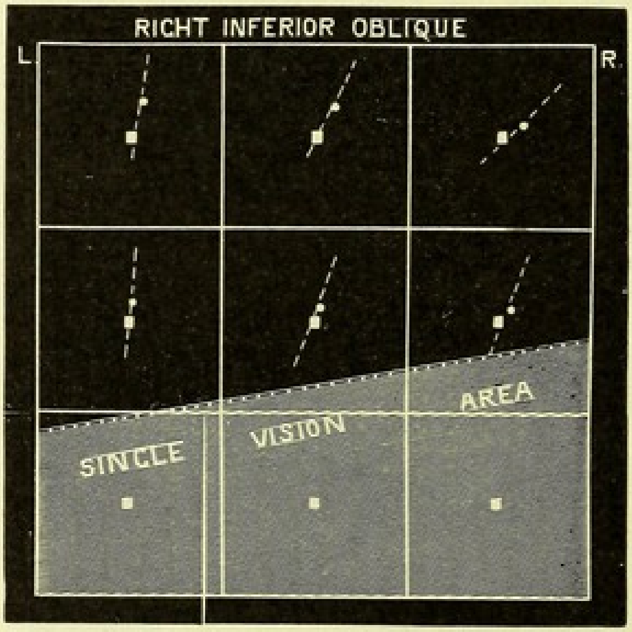


Fig. 67

**Diplopia.**—Vertical diplopia, greatest on looking up and to the left; torsional diplopia greatest on looking up and to the right; generally homonymous diplopia greatest on looking up and to the right, but sometimes crossed.

## Paralysis of Left Inferior Oblique

Same as the last, with substitution of right for left, and *vice versa* throughout the description. It turns the cornea *up* and *out*, with *extorsion*, and is a "dextral elevator."

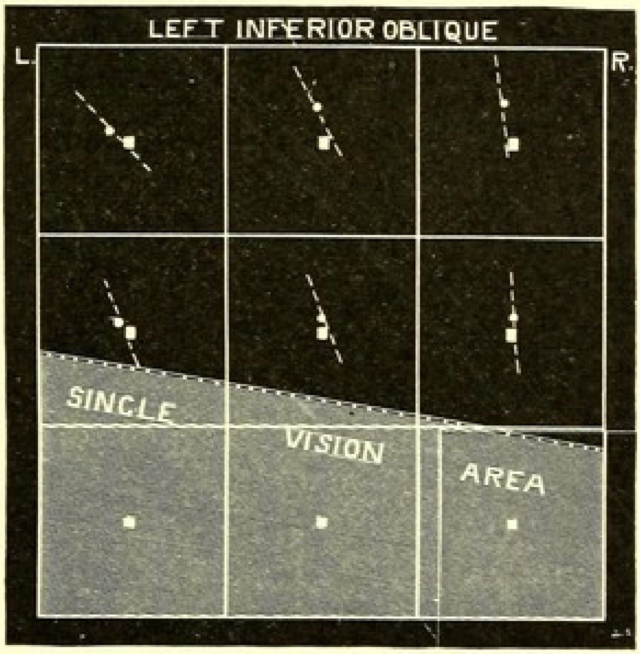


**Fig. 68**

There are several special points of interest about paralysis of the inferior oblique.

(*a*) It is a powerful elevator. Mauthner's observation that the vertical diplopia from paralysis of the inferior oblique is greater than that of the superior oblique, has been referred to.*

(*b*) Traumatic paralysis of this muscle from direct injury has been recorded by Noyes, Berry, etc.

(*c*) Since the short root of the lenticular ganglion is derived from the branch of the third nerve, which supplies the inferior oblique and conveys the motor fibres for the ciliary and sphincter iridis muscles, no posterior orbital paralysis of the nerve to the inferior oblique could occur without involving also the intrinsic muscles of the eye.

(*d*) It is highly probable, though not absolutely proved, that the nucleus for the inferior oblique lies on the opposite side of the median plane, necessitating a decussation of its fibers of origin analogous to that of the superior oblique. (Indeed, we may say

* It is interesting to observe, as perhaps related to this fact, that the insertions of the two obliques are not parallel to each other, but form a V, in such a way as to indicate that the inferior oblique has the greater vertical purchase of the two.

that the obliques are oblique in every way. They are innervated from the opposite side of the brain ; their maximum diplopia is on the side opposite to the affected eye, and is in every way oppositely named, being below when the oblique is above, and *vice versa.*) In unilateral nuclear paralysis of the third nerve it is of interest to *look* for paresis of the opposite inferior oblique, with escape of the inferior oblique on the paralyzed side. The evidence would be : (1) Defective upward movement of the good eye, especially on looking up and in. (2) Torsion of the good eye on looking up and out, causing *extorsion* of the image produced with the good eye by the glass-rod test. (3) Some upward movement of the lame eye, especially on looking up and in. (4) Extorsion of the lame eye (with intorsion of its image) on looking up and out.

## Paralysis of the Third Nerve

May be nuclear, sub-nuclear or peripheral ; partial or complete.

The extra-ocular muscles supplied by this nerve may be completely paralyzed (the superior, internal and inferior rectus, and inferior oblique, with the levator palpebræ) without any involvement of the intra-ocular muscles (the sphincter iridis and ciliary muscle) ; or *vice versa.* Such cases are almost certainly nuclear. On the other hand, partial involvement of some of the extra-ocular muscles, with only a partial participation of the intra-ocular, are almost certainly not nuclear.

**Signs.**—The outstanding features of a *complete* paralysis of the third nerve are :

(1) Ptosis, with vicarious contraction of the occipito-frontalis on that side.

(2) Abduction of the eye, increasing as time goes on, combined with slight subduction.

(3) Immobility of the eye in all directions except outwards, and outwards and downwards.

(4) Semi-dilated* pupil, immobile to light and to consensual influence.

(5) Loss of accommodation.

(6) The face generally looks straight forward, since it is not often that an attempt is made to overcome the diplopia. When such attempt is made, however, if the right eye be paralyzed, the

* As time wears on, the pupil becomes more fully dilated.

face looks to the left and slightly upwards ; if the left eye, the face looks to the right and slightly upwards.

**Pathetic Nerve.**—The most interesting fact to elicit is whether or not the fourth nerve is involved. The usual way of testing this is to make the sound eye follow the finger from above downwards, while the affected eye is closely watched to see if the cornea rotates about its own pupil like a wheel, under the influence of the superior oblique. That muscle being an intorter, rotates the upper part of

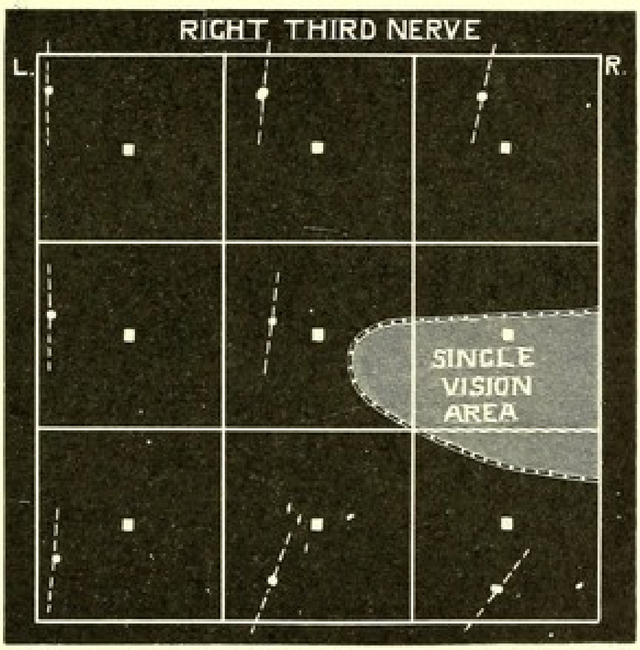


**Fig. 69**

the cornea inwards at the same time that it displaces the whole cornea down and out.

What I think a better plan is to hold one forefinger above and the other below the level of the patient's face, and make him look quickly from one to the other. It is always easier to detect a quick torsion than a slow one. If the superior oblique be paralyzed as well as the whole third nerve, the descent of the good eye produces no movement in the affected one.

Subjective measurement of the torsion by glass rods enables a more delicate test to be made than any objective test affords. In slight third-nerve pareses, raising the face will cause extorsion of the light streak if the fourth nerve be intact. In complete paralysis this test can be supplemented by making the patient keep his head still, cover his good eye with his hand and direct it alternately to the ceiling and the floor, while the glass rods are held before the paralyzed eye ; with the ophthalmoscope, too (as Hirschberg, according to Asher, first pointed out), torsional movement of the retinal vessels is well made out.

In estimating the amount of ptosis we must take into account that the overflow of nervous force into the occipito-frontalis muscle (on the same principle as the "secondary deviation" in the case of the ocular muscles), when an effort is made to raise a drooping lid, may cause a slight false elevation of the lid even when the levator is completely paralyzed. To guard against this fallacy the eyebrow has been recommended to be firmly fixed by pressure against the frontal bone before testing the power to raise the upper lid.

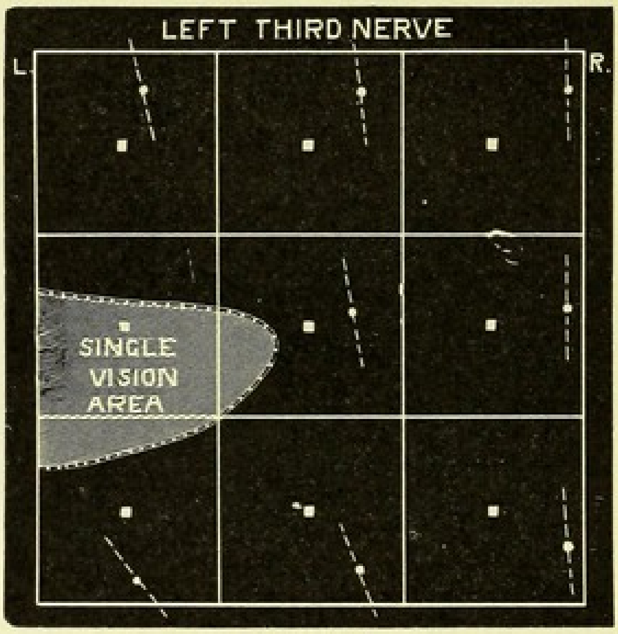


**Fig. 70**

Figs. 69 and 70 show, very diagrammatically, however, the nature of the diplopia in cases of third-nerve paralysis, after A. Fick.

## Measurement of Ocular Paralyses

**Measured Paralyses.**—It is always a good plan, when time permits, to take as accurate measurements as we can of the diplopia in all nine areas of the motor field. By repeating such measurements from time to time an excellent idea of the progress of the case is formed, and difficulties in the diagnosis may be cleared up. Actual measurements of the motility of the eye, though useful, are less reliable, since here much depends on the varying will-power of the patient and the amount of effort made.

**Mode of Measurement.**—The glass-rod test, used in conjunction with tangent scales adjusted on the wall, makes such measurements comparatively easy. A vertical scale should be suspended across the middle of the horizontal scale and a small but brilliant source of light be placed in front of their intersection.

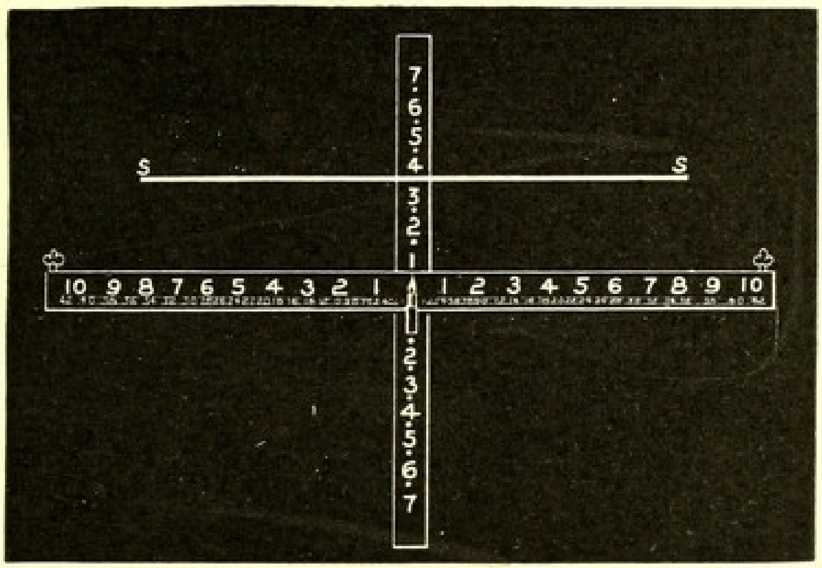


**Fig. 71**

Tangent Scales in degrees for five meters. The line *S S* represents the streak of light produced by the glass rods.

The patient, standing five meters away, should have his head posed in nine different attitudes, corresponding, as regards the eyes, to the nine motor areas, for the eyes themselves are to be directed towards the flame in front of the intersecting scales. A mounted series of rods being held, first horizontally and then vertically, before one eye, it is easy for the patient to read off the vertical and horizontal elements of the diplopia, in turn, for each attitude of the head.

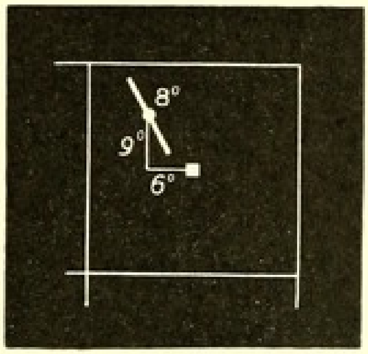


**Fig. 72**

**Entries.**—Fig. 72 shows a convenient way of noting down the results. Placing a dot in the center of each square to represent the true image, insert another dot to represent the false image, and numerate its horizontal and vertical elements as represented by the thinner lines, somewhat on the principle of rectangular co-ordinates, only in degrees instead of in linear units. If desired, even the degree of torsion can also be recorded, by finding what inclination must be imparted to the rods to make the streak of light appear vertical or horizontal.

**The Examination of Torsion Facilitated.**—The difficulty which has hitherto attended the investigation of the torsional elements of paralysis is very much lessened by the rod, for the patient's power of observation can be analyzed by tilting the streak slightly to one or other side, asking the patient to describe the inclination. In this way we learn just how much confidence to repose in his statements.

The record in Fig. 72 means that in the right superior area of the motor field the false image is displaced 6° to the left (lævoducted 6°), and 9° upwards (superducted 9°) above the true image, and has a lævotorsion of 8°.

A very good plan is to use mathematical paper, which is marked with very small squares, and to esteem each square a degree. If more space is needed, the true image need not, of course, be represented as in the center of the square, but can, for convenience, be displaced to any suitable corner, provided it be notified that the center of the square is the proper place for it, since it indicates the direction of vision of the sound eye.

The tangent scales described serve not only for paralyses, but also for heterophoria, for objective strabismometry and for prismetry.

As regards the *horizontal* displacement of a false image, it is well known that in paralysis of obliques a pre-existing latent divergence (exophoria) may be set free (*i. e.*, cease to be latent and become manifest) in the diplopic area of the field, and may so complicate the case as to convert the typical "homonymous" diplopia into "crossed."

A similar complication may occur, though less likely to do so, in paralyses of the superior and inferior recti, where there is a possibility of a pre-existing latent convergence (esophoria) converting the typical "crossed" dipiopia into "homonymous."

Further, with regard to *torsion* of the false image, Mauthner called particular attention to the untrustworthiness of the answers given by patients on this point, though it is true that by using the glass-rod test the difficulty is lessened, the tilting of a long streak of light being easily observed when compared with a vertical line on the wall.

In addition to this, I imagine that cases occur in which, however accurate the patient may be in describing the false image, the paralytic torsion is (at least in parts of the field) overborne by a greater pre-existing latent torsion exerted in the opposite sense so as to afford a misleading index.

In confirmation of this, it may be adduced that, on incidentally testing a refraction case, I found as much as 10° of latent extorsion associated with distant vision, which increased to 20° with vision for twenty inches. Such cases must be rather rare, but should they at any time subsequently develop paralysis of an extorting muscle (inferior rectus or inferior oblique), the latent condition would greatly complicate the torsion of the false image. The only way to detect it would be to study the torsion in all parts of the field.

In another patient (complicated, however, with inconcomitant hyperphoria, so that it was not so remarkable) I also found 10° of latent torsion in distant vision. Both were men, and had persistent tendency to headaches.

All these considerations accentuate the value of Mauthner's advice to pay attention only to the vertical element of the diplopia in paralysis of the torsion-producing muscles, at least for the rough primary diagnosis.

**Mnemonics.**—The mnemonic I would suggest as least misleading consists in so naming the areas of the field of diplopia that the area of greatest vertical diplopia shall be the namesake either of the affected muscle or of its true associate in the other eye. No diagram is needed for this and, happily, no arbitrary nomenclature of the areas is required, since their own proper names afford just what is wanted.

There is, therefore, no effort of memory, each area having its natural name from the patient's point of view.

Thus the *right superior* area is that which lies in the upper part of the field, to the patient's right. *Maximum vertical diplopia* found in this situation means paralysis of the namesake muscle, the *right superior* rectus, or else of its true associate in the other eye, the *left inferior* oblique. It is easy to settle between these two by finding to which eye the false image belongs.

The true associates can always be borne in mind by remembering that their names are the most contrary possible.*

In short, having found the area of greatest vertical diplopia, the paralyzed muscle is—*either the same-named rectus or the cross-named oblique.*

There are two plans of recording ocular paralyses at present: in one of these the surgeon transfers himself to the patient's position

*For example, *left inferior oblique* is, in every term, opposite to *right superior rectus*.

and looks at the motor field from the patient's point of view, as in Fig. 73, where the small print is borrowed from Eugene Fick.

In the other plan the surgeon selects the easier task of imagining himself where he really is, and looks at the motor field from his own side. It is as though a grating or a window frame were suspended in the air between the patient and himself the areas being

L. THE PATIENT LOOKS R.

| | | |
|---|---|---|
| Upwards to the left.<br>LEFT SUPERIOR AREA. | Upwards.<br>SUPERIOR MEDIAN AREA. | Upwards to the right.<br>RIGHT SUPERIOR AREA. |
| To the left.<br>LEFT EXTERNAL AREA. | Straight ahead.<br>PRIMARY AREA. | To the right.<br>RIGHT EXTERNAL AREA. |
| Downwards to the left.<br>LEFT INFERIOR AREA. | Downwards.<br>INFERIOR MEDIAN AREA. | Downwards to the right.<br>RIGHT INFERIOR AREA. |

**Fig. 73**
Author's Mnemonic Motor Field.

named by the patient, but looked at by the surgeon. These two plans correspond precisely to the two methods in vogue for recording the lenses in a trial frame.*

The "namesake" mnemonic just described answers in both modes of entry, since, in each, it is *the patient who names the areas.* Though I have hitherto used the second method the first seems in most common use, and in this work it has been adopted. For *confirmatory* evidences we need only remember the physiological action of the impeached muscle and that the image is displaced, when the eye is paralyzed, in every way like the eye would be displaced if it were sound.

*The inconvenience often experienced in translating one mode into another may be overcome by considering that one mode of entry looked at in a looking glass, or transferred by copying ink to a sheet of paper, or pricked through to the back of the paper yields the other mode of entry.

**Conjugate Deviations and Paralyses.**—In this group are included only those cases in which one or more of the conjugate *innervations* are affected, and never any case in which associated *muscles* may, as a coincidence, happen to be simultaneously paralyzed. We have already seen that probably all the co-ordinating innervations of the eyes are conjugate.

**Diplopia is not Characteristic.**—All the paralyses of *parallel* motion have this feature in common: that diplopia is either absent or inconsequential.

**Homonymous Restriction of the Motor Field.**—Only by undue *limitation* of the parallel motions of both eyes in one or more directions can defects in these motions be diagnosed.

**Convergence Defects.**—It is most likely that convergence defects divide themselves into—

(1) *Paralyses* of convergence of nuclear or supranuclear origin;

(2) *Insufficiency* of convergence, either latent, as in "exophoria," or too great to be suppressed, as in "concomitant divergent squint"; and

(3) *Absence* of convergence *effort*, from want of use when binocular fixation has been lacking for a number of years.

**Conjugate Elevation-Paralysis** means loss of the power of elevating the eyes. Numerous cases have been recorded. The more evanescent the paralysis, the more likely is its seat to be in the cortex. It may or may not be accompanied with ptosis.

**Spurious Variety.**—True conjugate elevation-paralysis, in which the two eyes are equally concerned, may be simulated occasionally by imperfect development of both superior recti, but is then nearly always conjoined with more or less of congenital bilateral ptosis. It is distinguished from true conjugate paralysis by efficiency of the inferior obliques, with characteristic diplopia accordingly, in the upper half of the field, the two images becoming crossed and inclined away from each other.

**Complications.**—When elevation-paralysis occurs as a nuclear affection, it is apt to be associated with more or less depression-paralysis, also with loss of converging power, and of its associated contraction of the pupil. In these cases the determination of accommodative power too should not be omitted.

**Conjugate Depression-Paralysis** rarely occurs alone. It is generally associated with loss of parallel upward motion as well.

Both have been completely lost, in many recorded cases, leaving the horizontal motions quite unaffected.

**Right-and-Left Motion.**—Conjugate parallel motions to the right or left may, for convenience, be called "ranging motions."

**Lost by Cortical Disturbance.**—They may be lost from sudden lesions in the cerebral cortex, causing, for a few days or weeks, inability to turn the eyes away from the side of the lesion ; the gradual restoration of power is due to the opposite hemisphere taking up the lost function, which happily is represented in both hemispheres.

**By Pontine Disturbance.**—If the lesion be in the pons, the rule is reversed, since the eyes now cannot be turned towards the side of the lesion.

**Conjugate Lateral Deviation.**—Passive deviation of both eyes to the right or to the left (corresponding to the "primary deviation" of an ordinary concomitant squint) results (*a*) from a cortical lesion on the same side as the deviation, or (*b*) from a pontine lesion on the opposite side.

**Lateral Spasm.**—Conjugate *spasm* is away from the side of a cortical lesion and towards a pontine lesion ; also towards the paralyzed side of the body, the limbs of which are rigid. "These are merely an extension to the eyes of effects of the disease manifest in the limbs" (Gowers). Thus irritative lesion of the posterior third of the left mid-frontal convolution may cause the patient to turn his eyes and his head to the right.

**Path of the Parallel Right-and-Left Innervation.**—The track of the innervation is from the cortical motor center to the corpora quadrigemina, thence to the opposite side of the pons (and probably through the superior olivary body) to the nucleus of the sixth nerve, where it divides equally into two, one proceeding along the sixth nerve to the external rectus of the same side ; the other to the nucleus of the third nerve for the internal rectus of the other eye.

Since the neurology of the subject does not properly, however, lie within the scope of this work, we now pass on to consider the *tests* for conjugate paralyses.

A—**Rough Tests.**

(1) *Finger Field.* Make the patient follow the finger (or some small striking test object) in all four cardinal directions, as previously described, to detect any defect in parallel excursions upwards, downwards, to right or to left.

(2) *Finger Near-Point of Convergence.* Approach the finger steadily towards the root of the nose, making the patient evoke every effort to fix the finger nail, till one eye commences to deviate. Notice at the same time if there is any contraction of the pupil associated with this convergence effort.

**B—Precise Tests.**

(1) *By Perimeter or Tangent Scale.* Place the patient's face in the perimeter and test the excursions of the eyes in each of the four cardinal directions. This may be done either objectively or subjectively.

OBJECTIVELY.—For the former, hold a lighted taper or electric lamp* at the normal limit of the motor field, close to the arm of the perimeter and screened from the surgeon's eye by a very small screen, which should be provided with a notch just opposite the flame. The patient's head should be immovably fixed, preferably by gripping something with his teeth, and with his face set straight for the central ivory disk. He should now be encouraged to attempt, as strongly as possible, to look in the direction of the flame, while the surgeon notes by the corneal reflection whether he actually succeeds.

If both eyes are tested together, the patient should have his chin placed centrally and be encouraged to accommodate for the distance of the arc.†

To test without convergence or accommodation, it is necessary to test each eye separately, placing each in the center of the perimeter in turn. When this is done, the greatest care should be taken not to let the patient fix anything in particular, since the convergence which accompanies any attempt to accommodate lessens the arc of abduction.

SUBJECTIVELY.—Subjectively, the test is easier to make, though not quite so satisfactory. A strip of paper with all the letters of the alphabet in line but out of order on it, large enough to be easily read by central fixation but too small for peripheral vision (J 7 is about the best size, I think) should be applied to the concave surface of the arm of the perimeter, while the patient is told to read the farthest letter he can distinguish (Casey Wood).

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*The most luxurious illumination is to have a small electric lamp fixed on the carrier of the perimeter.

†Instead of a perimeter, the distant tangent scale can be used, an assistant moving a flame along it, while the patient's head is held at a meter's distance by another assistant.

An instrument for measuring the field of fixation of the eye, called the tropometer, has been designed by Dr. Stevens. Whether it presents any advantage over the perimeter, is doubtful.

(2) **Precise Tests for Convergence.**—These can likewise be made both objectively and subjectively.

(*a*) *Manifest Strabismus.*—When a convergence paralyses becomes so great that actual divergent squint exists, it can be

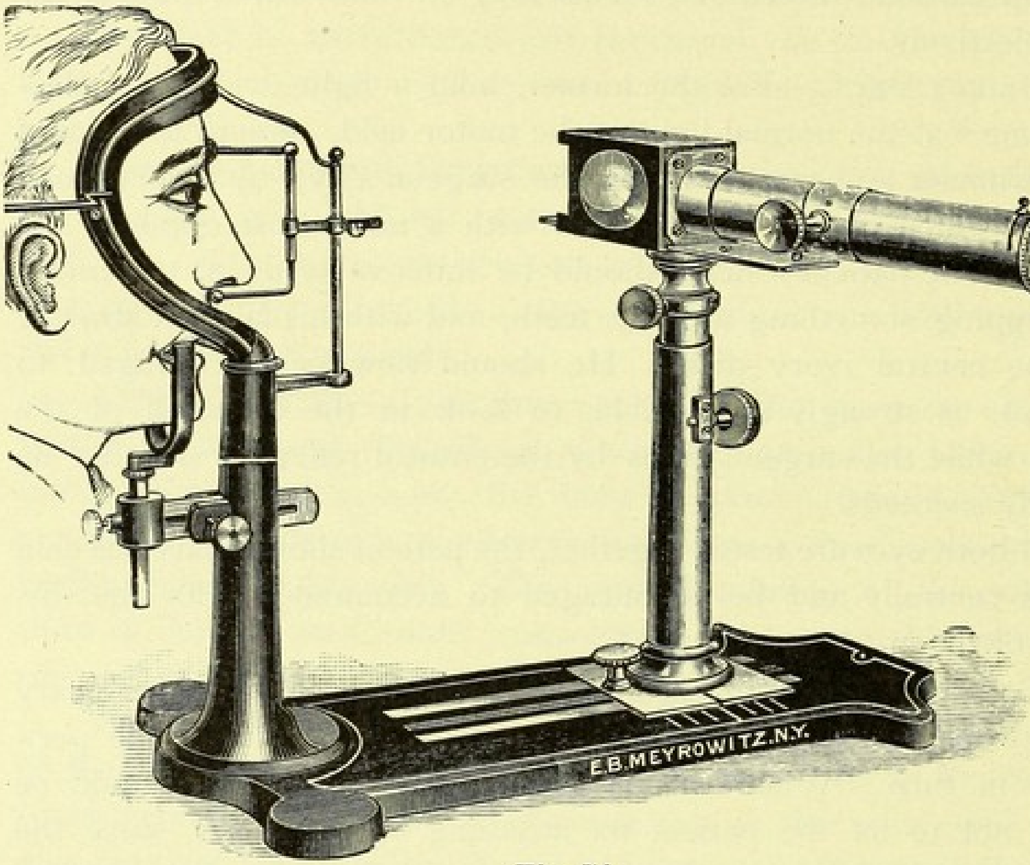


**Fig. 74**
**Steven's** Tropometer.

objectively measured either by Priestley Smith's tape method or by those described in Chapter VII, and subjectively by the rod test and tangent scale.

(*b*) *Convergence-effort.*—Besides measuring the squint, however, we wish to find how much convergence-effort remains alive, so to speak. The two stimuli capable of provoking it are :

(1) Accommodation, and

(2) The mental effort to converge by perceiving a near object : for even a blind person can converge, by mentally conceiving a near object.

Both of these stimuli to convergence (namely, accommodation and "knowledge of nearness") are introduced together when we make the patient regard a small approaching object.

What we do, therefore, is to carefully watch the squinting eye to see if the squint becomes less as we make an object travel straight toward the fixing eye.

If desirable, we may actually measure the convergence-effort on the perimeter, by first measuring the squint with distant vision and then with near vision of two or three small letters held on the end of a projecting arm fixed to the ivory button and pointing toward the fixing eye and sufficiently near to it to excite the maximum of accommodation.

It is but rarely that we need do this, or still less trouble to test the proportion between the accommodation element and the knowledge of nearness element : it can, however, be easily done by placing a concave lens before the fixing eye to elicit accommodation while the squint is measured at a distance, either objectively or subjectively.

# CHAPTER X

## Nystagmus

**Nystagmus** is a phenomenon of great interest, which, if thoroughly understood, would throw much light on the nature of ocular motions. It is absolutely involuntary, almost always simultaneous and symmetrical in the two eyes; and even when it is induced by making one eye look strongly in the direction of a single paralyzed muscle, so as to obtain the slight jerking movement which appears when the limit of muscular power has been reached ("liminal nystagmus"), a similar movement can generally be observed in the sound eye. This proves that the weak muscle is not the *seat* of the nystagmus, but only its *occasion.* It is really the conjugating center which has approached the limit of its power in the effort to stimulate an irresponsive muscle. It is only some kinds of nystagmus that can correctly be described by the word "oscillation." In the great majority of cases the movement resembles that of the flagellae of ciliated epithelium, the movements being quick in one direction and slower in the opposite. In horizontal or vertical nystagmus the quick movement is generally in the direction of any voluntary movement of the eyes to the right or left. In mild cases and those acquired in later life, the nystagmus appears only during voluntary movements of the eyes from the primary position, and this is especially so with miners, in whom the defect makes its appearance most readily when the eyes are directed upwards into the position required for their work. Nystagmus ceases during sleep, which fact is very instructive. Just as the converging innervation surrenders its activity during sleep, so as to make ordinary eyes diverge, and convergent squints to relax, so the other parallel innervations give up their tonic activity and nystagmus ceases. The kinetic energy expended throughout the day in some cases of nystagmus is really very great and shows how considerable are the activities of the conjugate centers.

**Varieties.**—The movements in nystagmus are so very various in kind as to point strongly to the separate existence of the several conjugating centers referred to in a previous chapter. "*Horizontal*" nystagmus is the most common. Next comes "*rotational*" nystagmus, in which the corneal meridians remain parallel with each other but experience simultaneous dextrotorsion and lævotorsion. Its existence affords evidence of two conjugating centers for torsion. "*Vertical*" nystagmus is less frequent still. It may occur alone, or combined with lateral movement (*mixed* nystagmus). "*Converging*" nystagmus, in which the two eyes approach each other and recede again, is extremely rare, but one case has been described by Gowers and another by Sym. Cases of "*unilateral*" nystagmus are met with and are rather difficult to explain, but they often are not examples of true jerking nystagmus but only of trembling of the eye.

In a few patients one kind of nystagmus succeeds another. It may, for example, be horizontal one moment and rotary the next, and would be well called "*protean*." It is not unlikely that in these cases one kind of nystagmus is evoked by one eye and the other kind by the other eye, and that each takes the lead alternately, imposing its own character of nystagmus on the other. The restless wanderings of totally blind eyes in adults doubtfully come under the heading of nystagmus; but "*searching*" nystagmus (Sym) is sometimes seen in patients of this kind, "the eyes passing from near the one canthus to near the other in a series of jerks, to return in one long sweeping movement."

**Rapidity.**—The rapidity of nystagmatic motions varies from 10 to 350 or more per minute. The excursions may be so small as to be only visible by the ophthalmoscope, or may be as large as one centimeter. Vertical nystagmus is always rapid; so, also, is nystagmus which dates from early childhood. Nystagmus due to exhausted innervations in adult life is also fairly quick; but where it is simply due to acquired total blindness, it is more frequently slow. The unilateral nystagmus of highly-amblyopic squinting eyes is usually slow, though Javal records a rapid vertical nystagmus in an eye of this kind. The unilateral nystagmus, however, which sometimes accompanies spasmus nutans is rapid.

**Apparent Motion.**—Nystagmus from infancy is unaccompanied by any apparent movement of objects, though, of course, their pictures are continually moving on the retina. This shows that the brain is conscious of the movements, estimates their measure and allows for them. It is probable that during the quick snatches no vision is effected, and only during the slower relapsing movement does it take place. In "miners' nystagmus" objects appear to move "either in a circle or ellipse" (Snell), which appears to show that only the lower co-ordinating centers are concerned. "It is sometimes accompanied by tremors of the head (perceptible to the hand placed thereon), of the eyelids and of the muscles of the face and neck." In some other rare forms of nystagmus the head moves synchronously, either *with* the quick motion of the nystagmus or against it.

**Examination of Nystagmus.**—There are three tests which should not be omitted.

(1) The *field of fixation*, which may be found limited in certain directions, corresponding generally to the positions in which the nystagmus is worst.

(2) The *position of least nystagmus* should be ascertained for each eye separately, by presenting a small object for the patient to scrutinize (Javal).

(3) Each eye should be *covered in turn*, to notice whether there is any difference in the character and time of the motions under the regime of each.

It is also advisable to examine the macular region for a fine central scotoma, and to note any error of refraction. In cases of total color blindness nystagmus is almost always present, since there is no central fixation, the macular region of the field being represented by a tiny central scotoma (Nettleship) due to inefficiency of the cones.

**Etiology.**—The chief causes may be classified as (*a*) vision defects; (*b*) neuromotor exhaustion; (*c*) organic disease. To this might be added a few rarer causes, such as reflexes, ataxies, etc.

Visual causes account for the greater proportion of the cases acquired in infancy. It is essential for this that both eyes should have their vision impaired during the early weeks of life when, under normal conditions, central fixation is being acquired. The defects of vision must be considerable at the time, though they may pass away afterwards, leaving the nystagmus.

Congenital cataract, ophthalmia neonatorum, or central chorido-retinitis, are the commonest causes. In adults, either complete blindness, or macular disease, is necessary. Even ripe cataract is not bad enough to cause it.

Neuromotor exhaustion accounts for miners' nystagmus, which is, therefore, functional rather than organic, and is always improved by complete change to an occupation no longer demanding the same direction of fixation. It is analogous to writers' cramp.

Pathological processes which cause nystagmus are very numerous. Almost any affection of the brain which impairs the vitality of the conjugate centers may cause it, and especially affections of the pons, cerebellum, corpora quadrigemina, peduncles and optic thalami. Affections of the semicircular canals also cause it. Sometimes pressure on the ear will cause it, and in one remarkable case of ear disease, inflation of the middle ear invariably caused nystagmus in one direction, while rarefaction of the air caused nystagmus in the opposite direction.

Nystagmus is an important symptom in "disseminated sclerosis," with "intentional tremor" of the limbs and exaggerated knee jerks. In "paralysis agitans," on the other hand, where the movements continue during rest and therein differ from those of nystagmus, the latter does not occur. The presence of nystagmus (on fixation only) in Friederich's ataxia is one of the distinguishing marks between this disease and locomotor ataxia.

**Nature of the Excursions.**—The peculiar character of the quick, jerking movement, with slower return, naturally tempts inquiry as to its meaning. It is, however, though unnoticed, a constant phenomenon of every-day life. As we walk along we may look at the ground or at objects around us. In either case, or, in fact, whenever there is *relative motion* between our bodies and neighboring objects, the eyes fix one salient point after another, experiencing a slow motion while looking at each, followed by a quick motion in the opposite direction in order to gain the next. Thus, when we look on the ground while walking along, the point of fixation does not run evenly along the ground, like a little dog, before us, but is quickly transferred from point to point, lingering on each long enough to give a good retinal picture but not too long to tire the retina. It is reasonable to expect, therefore, that the central apparatus should be so constructed as to facilitate movements of this kind and that when the centers are deranged they should occur spontaneously.

The great part played by visual defects in causing nystagmus is perhaps to be explained as follows: All ordinary visual actions combine a voluntary element with an involuntary reflex element. It is the latter which, after we have directed our eyes to an object, retains them there for a brief period. In nystagmus this retaining power is lost, so that the gaze is no sooner brought to bear upon an object by the usual quick movement than the eye moves away from it from want of the proper physiological support of reflex fixation. Any defect, therefore, in the reflex loop, whether from blindness or from imperfect development or education in early life, or from central or motor defects, will suffice to cause nystagmus.

When we turn round and round, the semicular canals inform us of the motion, and the eyes at the same time are caused by surrounding objects to make movements similar to those of nystagmus, the slow movements being opposite to that of the body and the quick ones with it. We can easily understand, therefore, that disease of the semicircular canals may cause nystagmus, since the two are so connected in daily life. Important conjectures have been made as to the mechanisms involved, but the proof is not yet complete.

**Treatment of Nystagmus.**—Operate as early in life as possible for congenital cataract or corneal leucomato. In older children correct the refraction, to give more rest to the nerve centers. Avoid over-fatigue of the eyes. If the position of least nystagmus for each eye separately be such that operations on the ocular muscles might make them coincide and other muscular weaknesses agree therewith, tenotomy or advancement might do good in exceptional cases. In miners' nystagmus, or that brought on by over-use of the eyes in certain directions, change of occupation with tonic treatment of the system generally, are indicated.

**Curiosities.**—Gowers records a case, with symptoms of cerebellar tumor and lateral nystagmus, in which the *pharynx* and *larynx* were the seat of similar movement ; "that in the pharynx was horizontal towards the middle line : in the larynx there was a similar lateral movement of the arytenoid cartilages." The rate of movement was the same as in the ocular muscles, 180 per minute.

Curiously enough, Javal has recorded a case of nystagmus in which the oscillations of the eye were arrested by the instillation of *atropine ;* while, on the other hand, Zehender records an instance in which the instillation of *eserin* provoked nystagmus. Peculiar varieties of nystagmus are met with in association with the "head nodding" of infants, which occurs as a transitory affection during the first year of life after the second month. The jerking of the head may be lateral, rotary or nutatory, but ceases in the recumbent position or during sleep, herein resembling nystagmus ; as also in becoming more pronounced when the attention is directed to an object. The nystagmus is frequently unilateral, and is "generally more marked on one side than on the other. Sometimes there is rotary or vertical nystagmus of one eye and distinctly horizontal movements of the other" (Thomson). Holding the head steady generally increases the nystagmus. In some cases there is rythmical contraction and dilation of the pupils. The occasional spells of lateral deviation of the head and eyes, sometimes associated with unconsciousness, suggestively indicate the mechanisms affected.

## CHAPTER XI

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# Ophthalmoscopic Corneal Images

Though the corneal reflections of candles, tapers, etc., have been used for a very long time, I believe the first published use of a reflection from the *ophthalmoscope* was by Priestley Smith, for his well-known tape method of strabismometry, about fifteen years ago.

When an eye is illuminated by reflection from an ophthalmoscope, a brilliant spot of light appears to rest on the cornea, produced, in reality, by reflection from the film of liquid on its surface, as from a strong convex mirror. This corneal reflection is shown in Fig. 78. The beginner in ophthalmoscopy is only too well acquainted with this spot, which gets in his way whenever he attempts to explore the fundus. It is well, therefore, to know its powers for good as well as evil, and in how great a variety of ways the very same reflection can be turned to account.

Corneal images produced by light reflected from a perforated mirror, such as that of an ophthalmoscope, afford far greater precision in the clinical investigation of the position of an eye than corneal images formed in any other way, provided attention be given to one or two simple details.

**First Precaution.**—The *first* precaution I like to insist on is that the patient's attention should be directed to the mirror, and preferably to its central aperture. Under these conditions the visual line of an observed eye coincides with the visual line of the observer's eye and the spot of light maps out with sufficient precision for clinical purposes, the point in each cornea which is traversed by the visual line.

Since the visual line does not generally traverse the center of the cornea, it is extremely convenient to have a way of so simply *seeing* where it lies in different eyes.

**The Second Precaution** is to avoid being misled by anomalies in the pupils, which are often placed differently in the two eyes. It is the position of the corneal reflection relative to the cornea, and not relative to the pupil, which we require to know, though we may conveniently use the pupil as a landmark by first noting the distance of its inner and outer margins from the corneal margin and then the place occupied within the pupil by the corneal reflection. It is generally, however, better to ignore the pupil altogether.

One great advantage of the ophthalmoscope for these reflections is that it is equally available in daylight and artificial light. In daylight the patient should stand with his back to the window and preferably at a good distance from it, while the observer, facing the window, reflects the light from it by the ophthalmoscope on to first one eye and then the other, directing the patient's attention to the aperture in the mirror that he (the observer) looks through. With artificial light, as when, for instance, the patient is seated for ophthalmoscopic exploration of the fundus, the best distance is from eight to twelve inches.

If we wish to decide whether a patient's squint is "apparent" or real, we have only to flash the light on to first one eye and then the other. If the corneal images occupy symmetrical positions in the two corneæ, as in Fig. 78, no squint exists, and in such a case

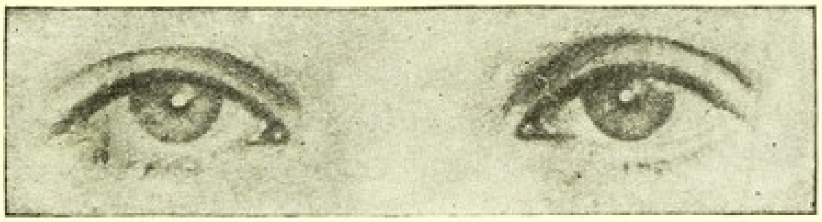


**Fig. 78***

Normal eye. (Photographed by author's squint camera.) To show the Corneal Image in an average eye; the pupil displaced slightly inwards and the corneal image displaced still more inwards.

the cause of an apparent squint will at once be evident from the fact that the corneal images in *both* eyes will be found to be symmetrically displaced from the usual fixation position, either both too much inwards or both too much outwards. But while symmetrical displacement explains apparent squint, marked unsymmetrical displacement shows real squint to exist.

With babies the test is of special service, for though they cannot, of course, fix the central aperture, they are fascinated by the bright light from the mirror, which answers almost as well, and then by *rapidly* flashing the light from one eye to the other, it is easy to see not only whether any deviation exists but also which is the

* Figs. 75, 76 and 77 in the original work were omitted by the author in this revised edition, which explains the break in the sequence of the figures at this point.

squinting eye. To be expert, a little practice is necessary, but the same is true of every method of examining the eyes. Many a perplexity would be at once dispelled if these corneal images came to the rescue.

**Fixation Position of the Corneal Reflection.**—When the vision of babies is imperfect, or the two eyes do not work well together, it is easy to find whether each eye possesses the power of central fixation by observing whether each corneal image occupies the "fixation position," with steadiness. In order to describe the "fixation position," let us mention a *third precaution* to be observed—namely, to allow for the *imperfect collimation of the visual line** and its variations. We will, for simplicity, suppose that the eye has only two axes, as in Fig. 79, viz., (1) the geometrical axis, and (2) the axis of vision, and explain these briefly :—

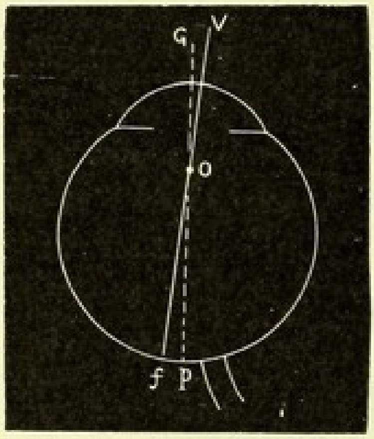



**Fig. 79**

To show the obliquity of the Visual Axis (*V f*) with reference to the Geometrical Axis (*G p*). The Fovea (*f*) is to the outer side of the posterior pole (*p*).

The optic axis (*G*) is the geometrical axis on which, so to speak, the eye is built, passing from the center of the cornea in front to the posterior pole of the eye behind. With this axis, however, the line of vision (*V*) does not coincide, for, curiously enough, we do not see straight out of our eyes, but obliquely out of them.

This is due to the fact that the "fovea centralis" (*f*) does not lie exactly at the posterior pole of the eye (*p*), but slightly to its outer side and below it.

Consequently, the line of vision (*V*) intersects the geometrical axis at the nodal points (*o*) of the eye, as shown at Fig. 79 (where, for simplicity, the two nodal points are reduced to one), and then traverses the cornea to the *inner* side of its center. In consequence of this the corneal image, visible while the patient looks at the center of the ophthalmoscopic mirror (and which, as we have already said, approximately maps out for us on the cornea the point traversed by the visual axis),

*This is not exactly the angle gamma, though it may be assumed to be practically identical with it. The *angle alpha* is the angle between the visual line and the major axis of the corneal ellipsoïd (now disproved), while the *angle gamma* is the angle between the line of fixation and the optic axis. The *visual line* passes from the point looked at through the nodal points to the fovea. The *line of fixation*, on the other hand, extends from the point looked at to the center of motion of the eye. The discrepancy between the aberration of the visual line and the angle gamma in a given eye is greater in proportion to the nearness of the object. *Donders' angle alpha*, since he assumed the major axis of the corneal ellipsoïd to coincide with the fore-and-aft axis of the eyeball, is the angle between this axis and the visual line.

appears to the inner side of the center of each cornea (see Fig. 78). The average aberration of the visual line is, in emmetropia, 5°. In hypermetropia the angle is greater, the average given by Donders being nearly 8°, and in myopia it is less, sometimes even negative, the average given by Donders being less than 2°. From the fact that Donders called this angle the angle alpha, some confusion has arisen in the use of that term. (See foot note, p. 200.)

**Apparent Squint.**—In consequence of these differences, hypermetropic eyes appear slightly divergent and myopic eyes slightly convergent, for we are so accustomed to the emmetropic aberration as to think any greater or less aberration peculiar, and hence arise the two well-known varieties of "apparent squint." The apparent position of the corneal image on the cornea, *while the center of the mirror is fixed* by the patient, may, as already mentioned, with advantage be called the "fixation position" of the image.

We have seen that in emmetropia the fixation position is to the inner side of the corneal center; in hypermetropia it is still farther to the inner side, because the angle gamma is greater; in myopia it is less to the inner side or even, in some cases, slightly to the outer side of the corneal center, because the angle gamma is smaller or even negative. In emmetropia the most common condition is, as represented in Figs. 78 and 80, for the pupil to be slightly to the inner side of the center of the cornea, and for the corneal image to be again slightly to the inner side of the center of the pupil. It is important, however, not to trust much to the position of the pupil lest it should mislead, and if the pupil be misplaced the position of the image in the cornea should be studied rather than its position in the pupil. In an eye free from nystagmus and which possesses the power of central fixation, the corneal image occupies the fixation position with great steadiness. If central fixation, however, be lost, the image is seen to wander aimlessly about the cornea, though really, of course, it is the cornea itself which wanders.

Priestley Smith has made the interesting and valuable observation that in tobacco amblyopia the power of central fixation is retained, while in some cases of acute retro-bulbar neuritis it is lost. An absolute scotoma involving the macula would, of course, destroy central fixation, which also might very likely be impaired by functional or organic changes at the macula, produced by looking at strong light or by over-use of the microscope, etc.

**Refraction Surmisable.**—With a little practice it is quite easy to surmise from the corneal image alone whether an eye is much hypermetropic or myopic, and I have pointed out elsewhere that a high angle gamma, as indicated by an unusually-displaced corneal image, should, in an apparently emmetropic eye, make us suspect the presence of latent hypermetropia and induce us to paralyze the accommodation.* It is well, however, to remember that exceptions to the rule are not infrequent.

The angle gamma in astigmatism does not appear to have been studied fully yet. In some cases of hypermetropic astigmatism in which the deficient curvature was horizontal, I noticed a greater angle alpha than in emmetropia ; and my impression is that, as a rule, a cornea which is too flat horizontally has a higher angle gamma than usual, whatever the vertical meridian may be.

The beauty of ophthalmoscopic corneal images is that we are able, as it were, to actually *see* in a moment what point of the cornea is traversed by the line of vision (cf. Figs. 78 and 79), and by the distance at which this point lies from the center of the cornea to guess approximately the amount of the angle gamma. Any instance of an unusually high or low angle at once strikes us and should set us to try and account for it by looking for some abnormal condition of refraction, eccentric fixation or unusual shape of the eye.

Clinical acknowledgment of the gamma is, I believe, the key to the successful use of ophthalmoscopic corneal images, and it is this which enforces the necessity of the patient's attention being directed to the mirror and, if possible, to its central aperture, since then, in normal eyes, the two images are symmetrical (Fig. 80). If the *same* eyes be allowed to wander to one or the other side, the images will, of course, appear unsymmetrical, for one will be nearer the edge of its cornea than the other, by a distance equal to twice the monocular aberration (Fig. 81). The vertical element of the angle alpha, shown by the corneal image lying generally slightly above the horizontal diameter of the cornea, seems of less clinical importance, and it is often imperceptible, though

*It may, perhaps, be well to explain that, since the cornea acts as a strong convex mirror, any image which is formed by reflection from its surface is, of course, a virtual image, the distance of which behind the cornea depends on the distance of the flame and the position and shape of the mirror ; but in fixation the depth of the image need not concern us, and we may regard the cornea, the pupil and the image as all in one plane. (The cornea is a mirror whose "principal focus" lies 4 mm. behind its anterior surface and, therefore, about the plane of the pupil.) The centers of the ocular media do not always lie in the optic axis, and this would, of course, affect the aberration, but clinically such considerations also can be waived. The existence of the aberration of the visual axis, then called angle alpha, was first proved by Senff, Helmholtz and Knapp, and its increase of magnitude in hypermetropia and decrease in myopia were subsequently demonstrated by Donders.

its amount is also subject to variation ; I have not devoted much attention to it, though noting many cases of very marked vertical displacement.

**Angle Gamma in Cataract and Iridectomy.**—It is very pretty to see how faithfully the corneal image occupies its correct "fixation position" in cases of lamellar cataract not quite large enough

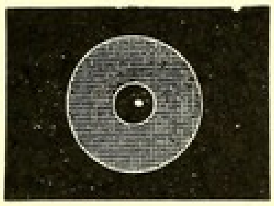
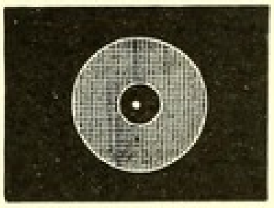


Fig. 80



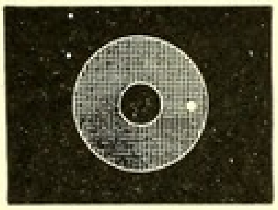
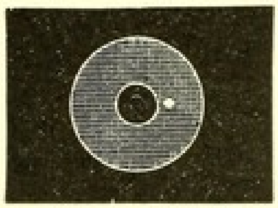


Fig. 81



To show the Symmetry of the images when normal eyes look straight at the mirror and the Asymmetry of the images when the same eyes look away from the mirror, though the eyes are not squinting. Fig. 80 shows how and Fig. 81 how *not* to use corneal images.

to fill the pupil, even though the reflection lies against the most opaque portion of the cataract. The visual line, therefore, traverses the cataract, as, of course, it would on simple optical principles. Similarly, in cases of very peripheral iridectomy for occluded pupil, and when the iris is drawn to one side, as in old cases of prolapse, the corneal image still occupies its proper position, though against an opaque background, and demonstrates, perhaps more prettily than anything else could do, the fallacy of supposing that a nasal or temporal iridectomy predisposes to strabismus or alters materially the relations between convergence and accommodation.

**Unsymmetrical Angles Gamma.**—Now let us consider a difficulty in the detection of strabismus by corneal images which arise very occasionally. The angle gamma may be different in the two eyes, so that the corneal images appear unsymmetrical. The asymmetry in these cases is, however, so slight that its very smallness leads us to suspect its true cause, and if we place the hand over each eye in turn, it will be found that the "fixation position" is not the same in each. Why, it may be asked, does the very smallness of the asymmetry lead us to suspect its true cause? The answer is: Because minute squints are exceedingly rare, except when one eye is blind or its image ignored, the natural desire for single vision being too strong to allow minute squints to exist without considerable efforts being made to overcome them.

In cases of alleged recent monocular blindness, the presence of a *very slight* squint affords presumptive evidence of the veracity of the patient, since a slight persistent squint cannot be voluntarily created. As, for instance, in the case of a young woman who stated that till a few days before she presented herself she had perfect sight in both eyes and that suddenly the sight of the left eye disappeared. No change could be detected in the fundus and the pupil reacted normally, so that the case looked like one of feigned amblyopia. Ophthalmoscopic corneal images, however, showed that there was a minute squint, and this corroborated the patient's statement.

**Alternation.**—A "monolateral" squint is one in which the same eye always fixes and the other always squints, in contrast to an "alternating" squint, in which latter either eye fixes indifferently. In squints of high degree it is most easy to determine whether they are alternating or monolateral, without the aid of corneal reflections, by simply covering the fixing eye for a few moments, so as to make the other one take up fixation instead; if the latter continues to fix

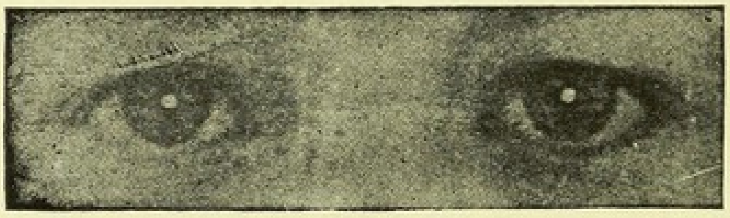


**Fig. 82**

Rather small Angle Gamma, especially in left eye, in a case of low myopia (.5 D.).

when uncovered, the squint is alternating, but if fixation is at once transferred back to the originally fixing eye, the squint is monolateral. With minute squints, however, it is not so easy to settle this point without the aid of corneal images, which enables us at once to see which is the fixing eye and whether, by covering this eye temporarily, fixation can be transferred to the other.

**Concomitancy.**—A still more important point to settle is that of "concomitancy," because by this alone can we tell whether or not a squint is *paralytic*. In paralytic squint the degree of strabismus increases on looking in the direction of action of paralyzed muscle; whereas, in concomitant squint, the degree remains the same in whatever direction the patient looks. The following method is one which I have found useful: Lay the palm of the left hand on the patient's head, with instructions to let the head follow the most gentle guidance of the hand without resistance. Now note the exact position of the corneal reflex in the squinting eye while the fixing eye is directed to the central aperture of the mirror, and steadily turn the head to the right and left, up and down and into intermediate positions, to notice whether the position of the reflection is unchanged by these manœuvres. If it is unchanged, the squint is concomitant; if otherwise, the squint is paralytic, provided that the movements made are not too great to bring in the fallacy of mechanical impediment from one of the corneæ reaching to its motor limits. Vertical squints are just as easily detected as horizontal ones.

**Test for Binocular Fixation.**—The next use of corneal images to describe is one which I have sometimes found of value, viz., to test for binocular fixation when its existence is doubtful.

After operating for strabismus and setting a squinting eye apparently perfectly straight, we are often at a loss to be sure whether both eyes are able to work together. We have some interest in finding this out, because binocular vision is so great a preservative from any return of the strabismus, and we can give a better prognosis accordingly. By subjective tests it is often impossible to settle the question, the patients being so frequently either too young or unintelligent to give us any assistance. An objective test, even though difficult and requiring a rather detailed description, is, therefore, a great help.

After operation, for some weeks at least, the eye operated on remains more stationary than its fellow (Berry), so that by turning the head slowly to the right or left we make, if binocular vision is absent, the corneal image on the squinting (and operated) eye slowly and steadily move across part of the cornea. If binocular vision be present, it *may* be strong enough to overcome the sluggishness of the squinting eye, in which case its image remains in the "fixation position" throughout. But even if the desire for single vision is not strong enough to effect this, there is always, if it be present at all, a part of the field of fixation over which the "fixation position" is maintained, and at the edge of this region the corneal image *suddenly* moves to another point. It is the continued maintenance of the fixation position during lateral movements of the head or else the sudden abandonment of the fixation position, instead of only gradually moving away from it, on which to count in making the test.*

**To Roughly Measure a Squint.**—Hirschberg has shown that when the corneal reflection of a flame occupies the margin of a medium-sized pupil (3½ mm.) the amount of squint present is 15° to 20°, and if it occupies the margin of the cornea about 45°. This convenient mode of guessing the amount of squint, of course, neglects the aberration of the visual line, for with normal aberration the corneal reflection lies nearer the inner than the outer margin of the cornea, so that a pupillary marginal reflection means a smaller divergent squint and a greater convergent one than the mean calculation. It is easy, however, to notice what the aberration actually is and to allow for it.

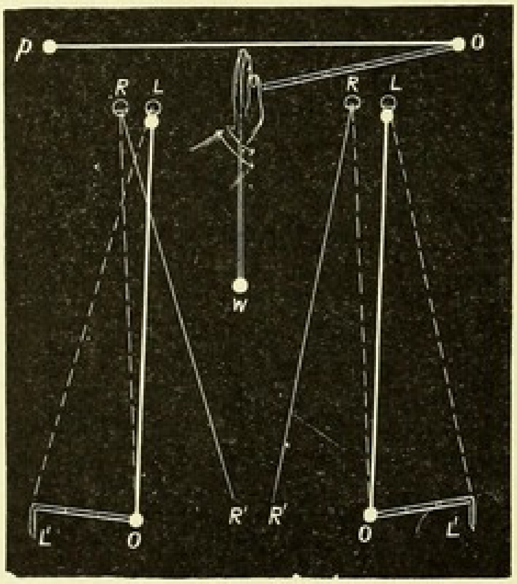



**Fig. 83**

Priestley Smith's Tape Method. The right-hand figure shows a diverging squint and the left-hand figure a converging one, both of the right eye. The ophthalmoscope is at *O* and the surgeon's hand at *L'*. When the fixing eye (*L*) is made to look at the surgeon's hand the squinting eye (*R*) becomes straight for the ophthalmoscope.

**Priestley Smith's Mode of Strabismometry.**—This excellent procedure was published so early as 1888. A piece of tape 1 m. (or 60 cm.) long, of which one end is held by the patient against his temple, while the other end is attached to a ring on the surgeon's finger. maintains the requisite distance between surgeon and patient. A second piece of tape, graduated and figured, is attached by one end to the same ring and then passed between the fingers of the surgeon's free hand, at which the patient is directed to look. When the separation of the surgeon's hands reaches the measure of the squint the corneal reflection occupies the normal position of the cornea of the squinting eye.

**Different Points of View.**—Students and onlookers some-

* "Ed. Med. Journ.," *loc. cit.*

times forget that they do not see the corneal reflections under the same conditions as the eye behind the ophthalmoscope. Fig. 84 shows a convex mirror illuminated from a point *L*. An eye placed at *I* sees an image at *1*, an eye placed at *II* an image at *2*, at *III* at *3*, at *IV* at *4*, at *V* at *5*, and so on; the reflections lying in a caustic curve.

**Error of Approximation.**—So far, I have assumed that the spot of light on the cornea marks the very point of its transit by the visual line. The assumption involves an exceedingly small error.

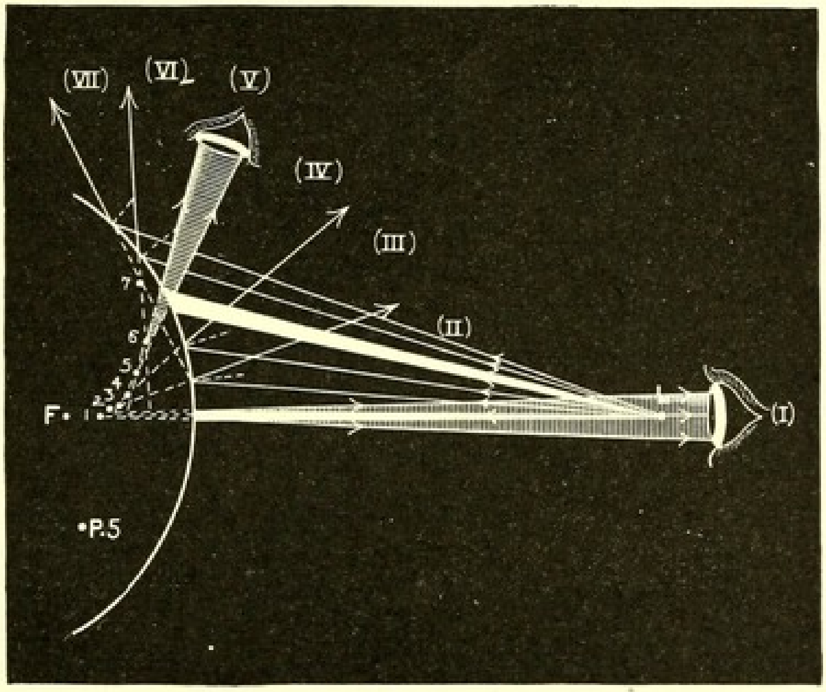



**Fig. 84**

The Caustic Curve of a convex mirror whose principal focus is at *F*

That the approximation should be trusted requires an analysis of the exact amount of error and its nature. Fig. 85 shows the principles involved.

A straight line connecting the center of curvature (*c*) of the cornea with the center of the sight-hole in the ophthalmoscope is the line which passes through the apparent center of the corneal reflection. Another straight line connecting the anterior nodal point (*N*) with the center of the sight-hole is the visual line. It will be seen that they do not quite coincide, and traverse the cornea at slightly different points, the difference being exaggerated in the figure to make it evident.

Without troubling the reader with calculations on so insignificant a subject, I make the corneal transit of the visual line at a distance from the anterior pole of the eye, which is only seven-eighths of that of the center of the corneal reflection. Hence, in emmetropia, where the corneal transit of the reflection is displaced on an average .63 mm. inwards, the displacement of the visual line is seven-eighths of this, the error of approximation being only $\frac{8}{100}$ of a millimeter.

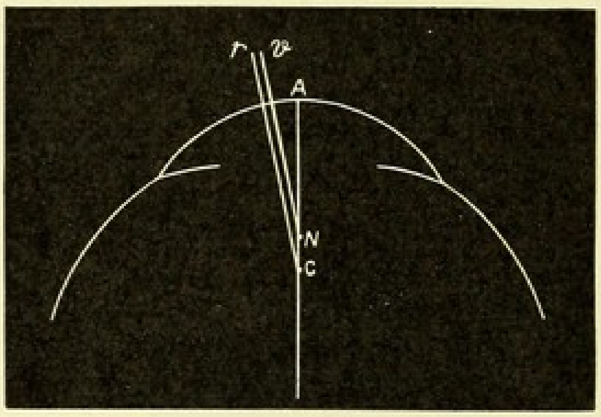



**Fig. 85**

To show that the Axis of Reflection (*r c*) is a little farther from the anterior pole than the Visual Axis (*v N*). *c* is the center of curvature of the cornea and *N* the nodal point.

The corneal reflection, therefore, very slightly exaggerates the real deviation of the visual line, but since it does so in a uniform proportion of 8 to 7, there is, for clinical purposes, no disadvantage in it. Since the *fixation line* proceeds from the center of motion to the object, the corneal reflection lies somewhere between the fixation and the visual lines.

**Photography of Muscular Anomalies.**—Hitherto, for permanent records of ocular paralyses, oculists have had to confine themselves pretty much to subjective hand-made charts of diplopia.

It is evident that photographic charts of the objective position of the eyes, free from all the fallacies of a subjective investigation, would be much better in some cases, and if carefully and properly utilized, the corneal reflections afford beautifully precise indices of ocular deviations of every kind except torsional.

Gullstrand (1892) made a number of photographs of muscular defects, utilizing the reflection from an ordinary window; but this source of illumination is not precise enough to afford such good results as are shown, for example, in Fig. 86, by marking out a much smaller point on each cornea through which the fixation line passes.

We have seen that to get the best results from ophthalmoscopic corneal reflections, it is essential that the patient should direct his attention to the central aperture of the mirror (Figs. 80, 81) and the surgeon's eye should be behind the virtual source of light (Fig. 84). To photograph the reflections perfectly, therefore, the light should proceed from the center of the photographic lens or else from an area surrounding the lens symmetrically, though indeed there would not be much error in lighting a flame or incandescent lamp just over the lens, while making the patient look at a point midway between the two.

Since daylight is the best, the camera which I have designed for the purpose (shown in Fig. 87) will probably be found the

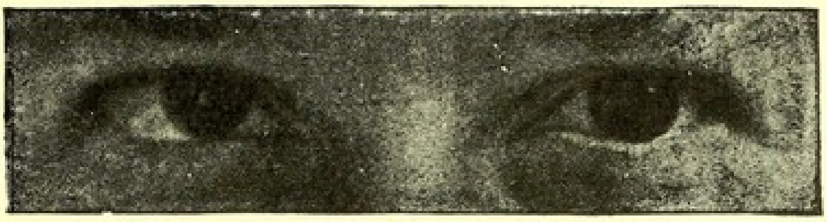


**Fig. 86**

High Angle Gamma in left eye, with ascending convergent Squint in the right.

handiest kind of apparatus to use, since it is meant for work out of doors where the greater intensity of light shortens the exposure—a point of great importance with so restless an organ as the eye. An elliptical mirror (*m n*) provided with an elliptical perforation nearer its lower than its upper end is fastened at an angle of 45° to a short cylinder of wood. This short cylinder is perforated and provided with a rapid portrait lens and pneumatic shutter. The wooden cylinder can be revolved round its axis, so as to bring the brightest part of the sky into view. To the patient the mirror, owing to its

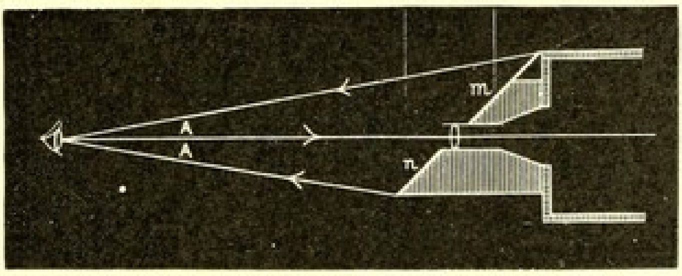



**Fig. 87**

Author's Squint Camera.

inclination, appears perfectly circular and makes a circular reflection on the cornea with a small black dot in the middle. Since the upper part of the mirror is farther from the patient than the lower, equal lengths there subtend smaller angles. For this reason the perforation of the mirror should be nearer its lower than its upper end, according to a simple calculation. The plane of the mirror should pass through the center of the photographic lens, and the major axis of the ellipse should be its minor as about 10 to 7.

If *d* be the distance of the patient from the lens and *b* be the breadth of the mirror, let *m* represent the required length of the mirror above the center of the lens and $n$ its length below, $\theta$ the inclination of the mirror to the horizontal and $a$ the angle it subtends at the eye. Then

$$m = \frac{b \cos. \frac{1}{2} a}{2 \sin. (\theta - \frac{1}{2} a)}$$

$$n = \frac{b \cos. \frac{1}{2} a}{2 \sin. (\theta + \frac{1}{2} a)}$$

Therefore,

$$\frac{m}{n} = \frac{\text{Sin. } (\theta + \frac{1}{2} a)}{\text{Sin. } (\theta - \frac{1}{2} a)}$$

and, since

$$b = 2\, d \tan. \tfrac{1}{2} a$$

$$a = 2 \tan.^{-1} \frac{b}{2\, d}$$

From these formulæ it is quite easy to construct a mirror for any inclination that may be most convenient, to subtend any given angle at the eye, and to appear as a perfect circle to it.

In practice, the use of my camera has given me much pleasure, for it only takes a minute or two to use. To save time, it is made in the form of a wooden box with a fixed focus. The patient's distance is adjusted by a stick of the right length and the box is provided with an Eastman film roll holder. To use the camera in the consulting room, seat the patient at one corner of the window with the side of his face about a foot from the glass. Place the camera in front of him (also about a foot from the glass) and with the mirror rotate 45° to catch the sky light and reflect it into his eyes. Bid the patient look at the center of the lens, adjust the distance of the camera with the stick and give about three-seconds'

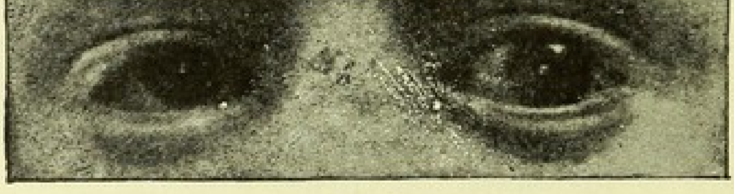


**Fig. 88**

Slight (temporary) over-correction of congenital defect of Right Superior Rectus, by advancement of the Superior and tenotomy of the Inferior Rectus.

exposure. Lately I have used the stand of Javal's ophthalmometer for the purpose. The instrument is removed and its place taken by a wooden platform for the camera to rest on. The patient rests his chin and forehead as usual. A tiny circle of paper affixed to the center of the lens for the patient to look at, does not impair the definition of the photograph.

For those who have not a special camera, it may be well to know that a mere disk of cardboard encircling the lens of any ordinary camera suffices to give a reflection from the cornea out of

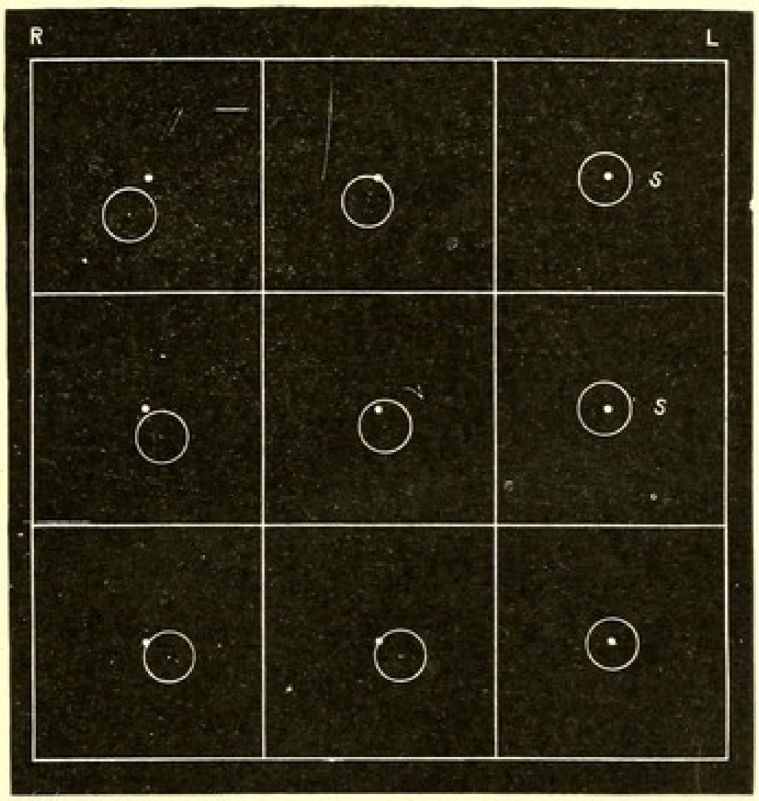



**Fig. 89**

Chart of the Corneal Reflections of the right eye, in a case of congenital defect of the Right Superior Rectus. Being a chart of objective appearances, the patient is supposed to be behind it, so that *R* and *L* are reversed.

doors, though not so excellent a one. Figs. 78, 86 and 88 were taken in this way by a skilful amateur. Since their publication I found that Gullstrand, in 1896, employed circular disks for the photographic investigation of the shape of the cornea, on the principle of Placido's disk ; so that the idea is not, in every part of it, a new one.

Indoors, in the absence of a mirror, a small incandescent lamp may be found convenient if fixed just over the lens, the patient being made to fix a point mid-way between the center of the lens and the center of the lamp. An acetylene flame is very suitable. But with a mirror no artificial light is needed at all.

Though a complete photographic record of an ocular paralysis would require nine photographs, yet for paralyses of single muscles three amply suffice: the first, with the head set in the favorite attitude; the second, with the eyes brought into the area of maximum diplopia; and the third, in the area on the same level as the last, but on the opposite side of the median plane. In each case it is only the head that is altered, since the eyes are made to fix the center of the lens always.

**Recording Reflections.**—Fig. 89 shows a simple plan of recording the corneal reflections of a case of paralysis, this being, indeed, a record, before operation, of the same case as Fig. 88. In the "left superior" and "left external" areas the reflections are normal, showing that single vision exists on looking in these directions. The "left inferior" area shows slight depression and adduction of the cornea. The median areas show depression increasing on looking up, combined with abduction in the superior median area, adduction in the primary area and still greater adduction in the inferior median. The right areas exhibit the same features in a more marked degree.

An extremely ingenious use of the corneal reflection has been made by Lucien Howe, who has used it to determine by graphic methods the actual rate of movement of the eyeball in glancing from one object to another, the record being made on a revolving sensitized cylinder timed by a tuning fork. His photographs thus taken appear to show that in glancing forty degrees the eye takes from one-tenth to one-twentieth of a second. This experimental method might with great advantage be applied to nystagmus.

## CHAPTER XII

# Heterophoria*

Latent deviations of the eyes involve the same principles as do the manifest deviations which we recognize as squints. They differ in being small enough to come within the overcoming power of the love of single vision, but are liberated from this superior influence in the dark ; or, when the vision of the two eyes is dissociated, by making single vision either impossible (prisms, etc.) or undesired (glass rod, etc.).

**Chief Divisions.**—Latent squints are, like manifest squints, grouped into "*paralytic*" and "*concomitant*," according or not as they steadily increase on looking in special directions.

**Dissociation of the Eyes.**—The demonstration of suppressed deviation depends on exclusion of one eye or on artificial diplopia of some kind, so as to "dissociate" the eyes ; or else on the arrangement of two objects, so that each is only seen by one eye.

By "dissociating" the eyes, we do not, of course, mean that any of the innervations are made to cease to be conjugate, but merely that the desire for single vision is removed so that the eyes fall into their "position of equilibrium."

Thus, if a strong prism, with its apex upwards, be held before one eye, everything appears double, and the distance between the double images of any object as, *e. g.*, a candle, is so great that the cerebral centers concerned, utterly unaccustomed to so great a separation between the images of a single object, make little or no attempt to unite them. The eyes are now said to be "dissociated," and if any latent deviation exist it will express itself by a movement of one image to the right or left of an imaginary vertical line passing through the other.

This device for dissociation, as introduced by v. Graefe, was for many years a favorite. It requires considerable care in the adjustment of the prism, for since the image seen through the prism is displaced in the direction of its apex, it follows that if the apex is not exactly vertical, neither will the said image be situated vertically over its fellow if no deviation exist. Thus, a lateral

* Heterophoria is Stevens' name for latent deviations.

displacement of the image due to a badly-placed prism may be wrongly attributed to the eye. Since, to begin with, prisms are often incorrectly marked, precautions have to be taken accordingly and the prism be set in the trial frame so that a vertical line seen through it appears unbroken throughout.

**Physiological Heterophoria.**—Within certain limits suppressed deviations are physiological, for though the accommodating and converging centers are functionally connected in a very intimate way, they are not indivisibly one. Exclusion of one eye, while the other is engaged in distant vision, causes the excluded eye generally to deviate little, if at all, inwards or outwards from its former position. As the object fixed is brought nearer, the eyes converge less than they accommodate with each approach. In consequence of this we find that, if the excluded eye deviates outwards in distant vision, the deviation increases more and more as vision becomes nearer.* By the time the object is within a foot of the eyes, the deviation has increased to 3° or 4°, in the majority of people.

It follows from this that in ordinary close work we habitually suppress, by our desire for single vision, a deviation to this extent. Were the same deviation to exist with both eyes uncovered, we would, of course, see double ; but the love of single vision will not allow it to exist under those circumstances.

The unconscious effort required to suppress a deviation of normal amount in the interests of single vision is so slight that we experience no inconvenience from it. But if, from any cause, the deviation be a great one, the effort demanded may be sufficient to occasion headache or asthenopia, and the more so if there be any debility of the system. Indeed, the effort may at times be given up, double vision being accepted until the tired centers have had time to recuperate themselves for a fresh attempt at single vision. One form of "periodic strabismus" is of this nature.

**Direction of Deviation.**—An excluded eye may deviate in any direction, upwards, downwards, inwards or outwards, or in intermediate directions ; but in the last case we think of the horizontal element and the vertical element separately. Since the power of elevating or depressing one eye above or below the other (monocular sursumduction or deorsumduction) has much smaller physio-

*Syme "Fellowship Essay," 1882, and "Trans. Oph. Soc.," 1883, p. 290.

logical limits than horizontal powers of adjustment, it follows that vertical deviations are of so much the more importance than horizontal.

**Hyperphoria.**—Since, in concomitant vertical deviations we cannot tell which eye is at fault, the convenient name "hyperphoria" was introduced by Stevens. Instead of speaking of an upward or downward deviation of one eye, which would give us two things to remember, viz., which eye and which direction, he speaks of a right or left hyperphoria, which gives us only one thing to remember. Thus, if the right eye deviate downwards on exclusion, he calls it a left hyperphoria.

We need, however, to always test both eyes to assure ourselves that the deviation, even if it seem concomitant at first, is of the ordinary kind, for during an extended investigation made for Mr. Berry among the patients attending his out-patient department, several cases were found in which *each* eye deviated upwards on exclusion. And, besides this, the use of the term hyperphoria should not make us forget that the deviation may be paretic and due to actual weakness of a muscle, causing the separation of double images to be greater in some directions, and to be greater when the paretic eye fixes (answering to the secondary deviation) than when the sound eye fixes (answering to the primary deviation).

The following are the best tests for latent deviations :

(1) **The Objective Screen Test.**—Make the patient fix a very definite test object, near or distant, as may be desired. Screen one eye for fully half a minute. Suddenly withdraw the screen, watching if the eye makes an instantaneous movement of recovery ("corrective movement"), and if so, in what direction.

A corrective movement *inwards* would show that the eye had wandered outwards under the screen, so as to betray a latent divergence (*exophoria**).

A similar corrective movement *outwards* would betray a latent convergence (*esophoria**).

Vertical corrective movements show that one eye has latent elevation (hyperphoria) or latent depression.

These tests can be made a little more delicate by employing a flame for the patient to look at, or by throwing light on one eye, before covering it, from the mirror of the ophthalmoscope. On momentary unscreening of the eye the position of the corneal

* Dr. Stevens' terms.

reflection can be observed before the eye has had time to recover itself.

Graefe recommended that both eyes be shut for a little while befoie making any test for latent deviation.

(2) **Subjective Screen Test.**—Alfred Graefe pointed out that when one eye has a manifest deviation, however small, sudden screening of the fixing eye makes a candle flame appear to the patient to move, for the deviating eye makes a corrective movement in order to take up fixation, and this movement betrays itself by an apparent displacement of its field of vision.

The same principle has been applied to latent deviations by Duane, who has called it the "parallax test." After covering one eye for a time, he suddenly transfers the screen to the other. If the first eye wandered under the screen, the deviation is betrayed by a sudden apparent displacement of the candle in the *opposite* direction to that in which the eye deviated.

Thus, if the right eye be the one first screened and the flame moves to the right, there is esophoria ; but if the flame moves to the left, exophoria. Duane calls them respectively "homonymous parallax" (P//) and "crossed parallax" (PX). If the flame moves down, he calls it "right parallax" (PR), because it shows that the right eye deviates upwards (right hyperphoria) ; and if the flame moves up, "left parallax" (PL), showing left hyperphoria.

This test presents the advantage of requiring no apparatus. Otherwise, its usefulness is doubtful except for a skilled patient. Parallax "can be measured in terms of the prism which causes its abolition." For near vision, a dot on a piece of paper replaces the flame.

(3) **Prism Tests.**—These were introduced by von Graefe long ago. A prism, with its base up or down, strong enough to produce insuperable vertical diplopia, was held before one eye, while the patient looked either at a distant flame or at a dot on a card (with a vertical line through it, which, however, it is better without).

If one image appeared to wander to the right or left of the other, the eye to which it belonged was proved to have deviated in the opposite sense.

The amount of deviation was measured by the prism, base in or out, required to bring the two images again into one vertical line.

The difficulty of ensuring that a prism is strictly base up or down, and the considerable inaccuracies introduced by even slight departures from a correct position, led the writer to design a "double prism," shown in Fig. 90, like two thin prisms joined at their bases but made of one piece of glass and somewhat similar, therefore, to the bi-prism used by Fresnel to demonstrate phenomena of interference.

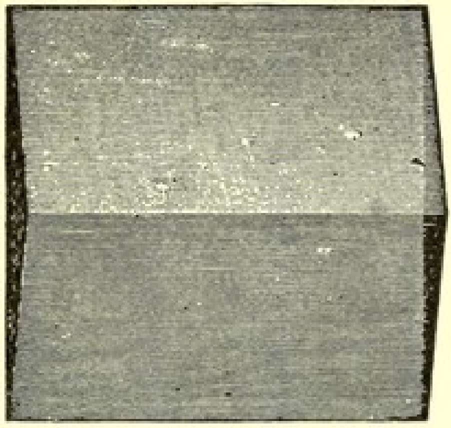


**Fig. 90**
Double Prism (square form)

When this is held before one eye of the patient he sees with that eye two images of a flame, one above and the other below, the real image seen by the naked eye. When the two false images are vertical, the prism is correctly held and it is easy to judge whether the third and real image lies to the right or left of the imaginary line between them.

Dr. Stevens, of New York, feeling the same difficulty about Graefe's prism, overcame it in a different way—by his excellent and well-known "phorometer," in which prisms are mechanically

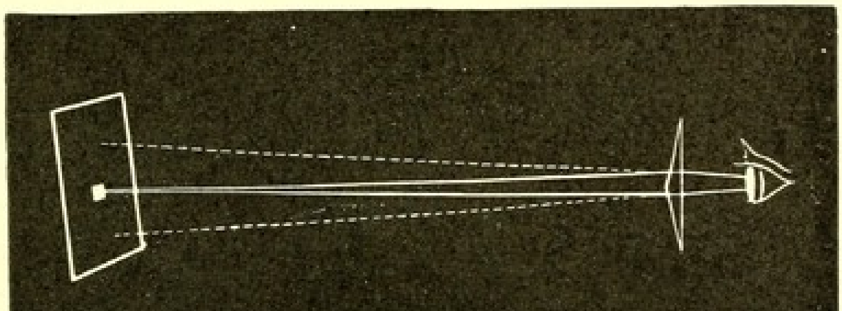


**Fig. 91**
Side view of a Double Prism. (From "Journ. Anat. and Phys.," vol xx, p. 496)

geared together in a stand, as shown in Fig. 92. Numerous phorometers have since been made by others, many of them of excellence (*e. g.*, Prince's, Risley's, etc.). Most of these, however, are expensive and possess no advantage over the simpler glass rods, to be next described.

It should, perhaps, be noticed that in all tests in which the eyes are dissociated by the prisms, the *desire* for uniting the double images is not wholly abrogated, but only the *power* to do so taken away. Unless, therefore, the separation of the two images be considerable, there is a tendency to bring them into one vertical line. This tendency, however, if a strong prism be used, is quite slight and insignificant, and is, I think, removed altogether if the images are made quite dissimilar, as in the next test.

(4) **The Glass-Rod Test and its Allies.**—Owing to imperfect manufacture of the double prism, described in the last section, the

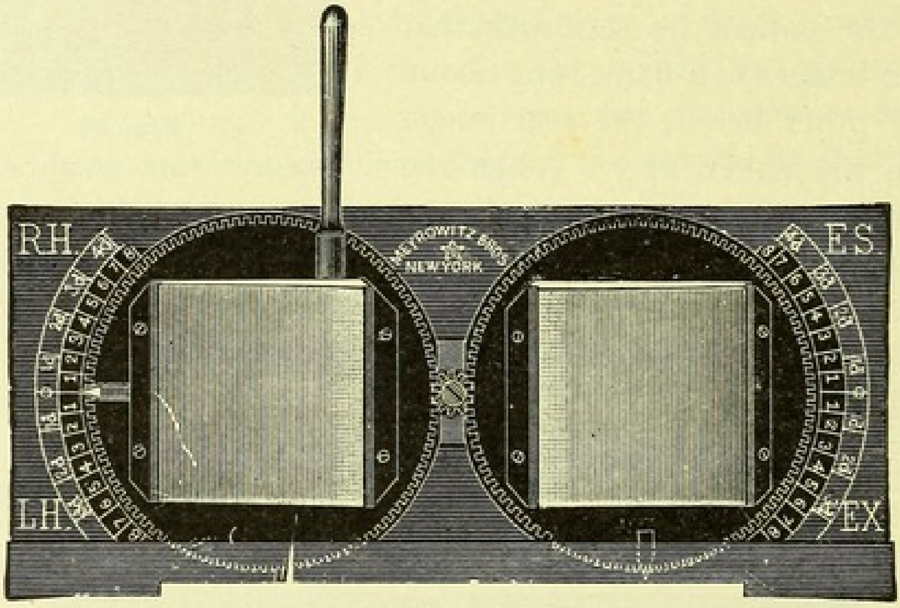



**Fig. 92**

**The Prisms of Stevens' Phorometer**

ridge had a rounded instead of a sharp edge, and this caused the appearance of a faint band of light * joining the two false images. It was this band of light which led me to employ a glass rod to produce a more pronounced streak of light. This simple "rod test" does not, like the prism tests, depend on separation of the two images of an object, but on alteration of the *shape* of one of the images so that it is no longer recognized as belonging to the same object.

**Optical Explanation.**—When a point of light is viewed through a transparent cylinder it appears drawn out into a line of light at right angles to the axis of the cylinder, for the simple reason that

* Mr. Berry noticed this band was transversely striated, and showed the striations to be many of them due to the phenomenon of "interference." If Mr Berry had not taken so much interest in this band, I might not have attended to it sufficiently to have thought of the possible utility of it and the reproduction of it by a glass rod.

the radiant point is put out of focus for the retina in this meridian but not in that which corresponds to the axis.

It forms, in fact, a "diffusion line"; just as a strong spherical lens by acting equally in all meridians forms a "diffusion circle."

The whole light which emerges from the cylinder thins down like a wedge into a line, parallel to the axis, from which it again spreads out on to the cornea to be collected finally into a line, perpendicular to the former line, on the retina. The length of the diffusion line thus thrown on the retina is exactly that of the diameter of the diffusion circle created by a spherical lens of the same power.

If the other eye, which has no rod before it, be open, the flame is seen by it nakedly, and since a line and a flame are not mentally conceived to be double images of the same object, the desire to unite them is quenched for the time, and all the more so if they are differently colored by making the rod of red glass and holding a plane blue or green disk before the other eye.

**Two Species of Cylinder.**—Since a long line is a desideratum, we must use a strong cylinder to produce it. The form of cylinder at first used was a simple glass rod, to be found almost everywhere, such as a stirring rod, thermometer tube, etc., whence the name of "rod test" was that originally employed.

I found, later, by experiment, that a more perfect line and a greater conservation of light is obtained by a plano-cylinder of such a strength that when held as close to the eye as practicable, the principal focus shall lie in the plane of the pupil. It differs from the glass rod in that the light which traverses it is focused within the eye only, without first being narrowed up into a line before reaching the cornea.

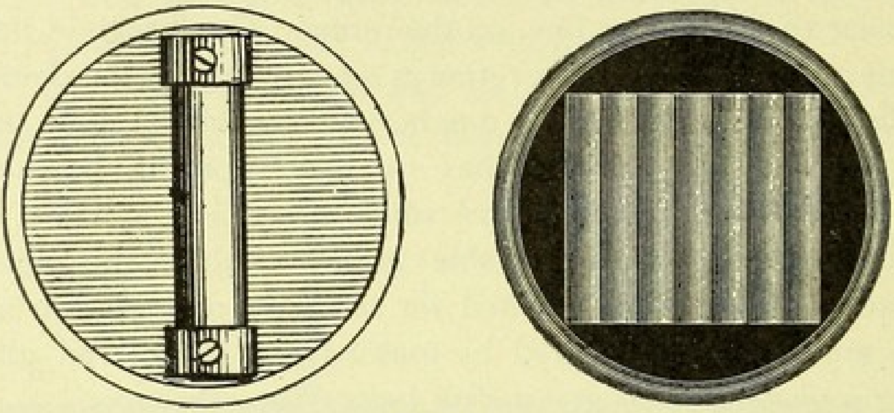
This cylindrical lens, already described, though optically more perfect, is not nearly so useful clinically as a series of mounted rods. A plano-convex cylindrical lens* with a radius of curvature of about 10 mm. is the one which when held at the usual distance from the eye, admits the maximum of light through the pupil.

With such a lens, so little light is lost that even the stars can be used to test the equilibrium of the eyes. Immense distances, however, seem to give the same results as moderate ones.

The line produced by a star is of exquisite delicacy. While this form of cylinder gives a brighter and more even line than any

* In my first description of this lens ("Oph. Review," vol. xii, p. 40) for "radius of curvature" read "focal length." The actual lens I had been using had a radius of curvature of 10 mm. and a focal length, therefore, of about 20 mm.

other, it needs more careful placing before the pupil than the group of glass rods already described, and this spoils it for rapid clinical work. Swan Burnett suggested a weaker cylinder still, moved up and down before the eye to compensate for the shortness of the line, and in the absence of a special instrument, a cylindrical lens from the trial case can be thus utilized.



*a* **Fig. 93** *b*

(*a*) The first form of the Glass Rod Test : now converted into (*b*) a row of glass rods.

**Manufacture.**—The rod should be free from flaws and from tapering, and to prevent the flame being seen past its edges, if only a single rod be used, it should be mounted in a slit cut out of the central part of a circular metal or vulcanite disk. This is shown in Fig. 93, the use of the disk being to exclude all light from entering the eye except that which traverses the glass cylinder.

Probably the best form of instrument is the modification suggested by Mr. Berry, viz., a piece of plane glass corrugated or grooved with rounded linear elevations and depressions ; but, owing to its difficulty of manufacture, I chose rather to fix together a number of small glass rods side by side. When this is carefully done, so that the line of light produced by each rod forms part of the whole line without distortion, we obtain a longer total line of light and require the exercise of less care in placing the apparatus before the pupil. The superiority of the multiple rods over the single rod is at once evident on using them.

It is easy, after laying a row of short rods side by side on a smooth surface, such as that of a mantelpiece, to cement their ends together with sealing wax. For good work, however, they should be mounted in a metal or vulcanite disk.*

* The diameter of the disk to which the axes of the rods are parallel should be carefully marked upon it, and also the diameter at right angles to this.

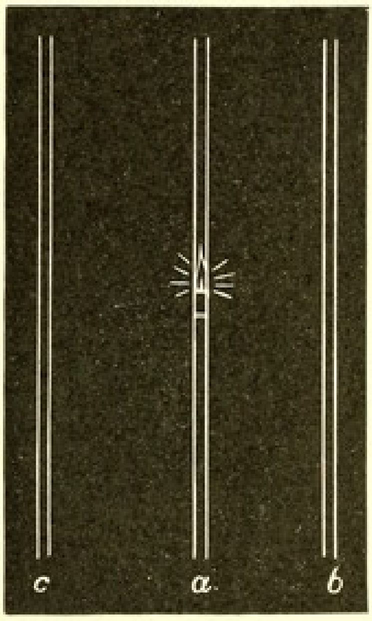
**Mode of Use.**—Whatever form of rod or cylinder be employed (since the line of light is always, of necessity, at right angles to the axis), if we wish to produce a vertical streak (with which to test horizontal deviations) the axis must be held horizontally, and to produce a horizontal streak (with which to test vertical deviations) it must be held vertically.

Though not essential, the test is greatly improved by using rods of red glass and holding a piece of green or blue glass before the other eye. This makes the streak and the flame differently tinted and also makes the streak more visible by subduing the excessive brilliancy of the flame.

Since the streak of light is of exactly the same breadth as the flame, a candle gives a good vertical band, but a feebler and broader horizontal one. When we test for vertical deviations, therefore, it is better either to use, as I do, a miniature lamp, or else a gas jet turned low and not more than a quarter of an inch in height. A small toy paraffine lamp answers beautifully, especially with black velvet behind it.

The patient should be placed at a distance of not less than 5 or 6 meters from the flame. Distances greater than this, even ten or twenty miles away, as when a lighthouse is viewed at sea, give practically the same results.

We begin by holding the rod horizontally to test for a *horizontal* deviation. If the line of light appear to pass through the flame, as (*a*) in Fig. 94, the balance is perfect. If it lie notably to one or other side of it, as (*b*) or (*c*) in the same figure, a deviation exists to an amount proportionate to the distance apart.




F g. 94
Use of Rod Test.

If the line be to the same side of the flame as the glass rod, the diplopia is evidently direct (*i. e.*, homonymous), indicating latent convergence (esophoria); if to the other side, the diplopia is crossed (*i. e.*, heteronymous) indicating latent divergence (exophoria).

To note the *vertical* equilibrium, we next rotate the rod into the vertical position, which produces a horizontal line of light. In the vast majority of patients this line will be found to pass almost exactly through the flame. Should it lie above the flame, it indicates a downward deviation of the eye before which the glass rod is held ; but if below the flame, it indicates an upward deviation of the eye. It is easy to remember the old rule, that the deviation of an eye is in the opposite direction to that of its false image, which applies to both vertical and horizontal deviations.*

**Measurement of Latent Deviations.**—(1) The extent of a deviation may, in the absence of a scale, be roughly estimated by finding at what horizontal or vertical distance from the flame an object may be placed on the wall to be crossed by the streak of light.

(2) If a tape measure coiled up in a metal box be available, a very good way is to hold the zero of the scale just behind the flame and draw out the box till it meets the line of light.

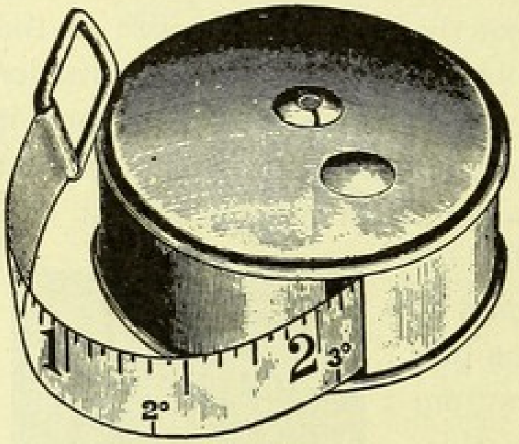


**Fig. 95**
**Tape marked in Tangents of Degrees, as well as in Centimeters**

This method, like the last, however, is subject to the drawback that, to leave the observer free to make the measurement, the rod must be placed in a trial frame or be held by the patient himself. We need only divide the number of centimeters recorded on the tape by the number of meters the patient stands away from the flame, to get the deviation of the eye expressed in prism diopters. To convert this approximately into degrees, multiply by 4 and divide by 7, since a prism diopter is four-sevenths of a degree. Since each succeeding prism diopter has a smaller value than the last, the unit is a bad one for high deviations. The degree is still the best unit, unless, perhaps, for the decentering of lenses.

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***A Rare Anomaly.**—I have noticed in some rare cases of strabismus that the deviation of an eye which is totally excluded from vision is different from its deviation when its exclusion is not total, even though the deviating eye takes no share in fixation. In addition, therefore, to placing the rod before one eye, it is sometimes well to exclude that eye and expose it momentarily, that the line of light may be seen in a position answering to the deviation on exclusion. It is easy to do this by holding one side of the metal disk which bears the rods before the pupil and then steadily moving the rod across the line of vision till the pupil is again covered by the other side of the disk. The streak is thus visible for a moment and is again extinguished before the eye has time to redress itself. The result of this test in ordinary cases will nearly, if indeed not quite, always be found to coincide with that obtained by keeping the rod always before the pupil, showing that in the vast majority of cases the ordinary use of the rod reveals as much of the latent conditions as complete exclusion would do, and this is still further ensured if the recommendation to hold a colored glass before the other eye be observed.

(3) When the patient has a visual acuity too poor to read the figures on a tangent scale, *prisms* may be used to measure the deviation, that prism which brings the streak and the flame together (provided it be held with its base-apex line perpendicular to the streak) being the one whose *deviating* angle expresses the deviation. Many ingenious prismatic contrivances, the description of which belongs to another work, have been made to dispense with a number of prisms ; and some of these, such as Prince's phorometer, Jackson's triple rotary prism and Risley's prisms, have been combined with the rod test and do their work well.

(4) *Tangent scales*, for permanent fixtures on the wall of the consulting room, afford the method which I prefer to any other. These scales are now constructed both for horizontal and vertical deviations, as shown at Fig. 96. They are graduated for use at 5 meters and are marked with large figures representing degrees* of deviation, these figures being in black to the right and in red to the left of the scale. The zero is at the center, and there a tiny paraffin lamp is fixed with a small piece of black velvet behind it, to heighten

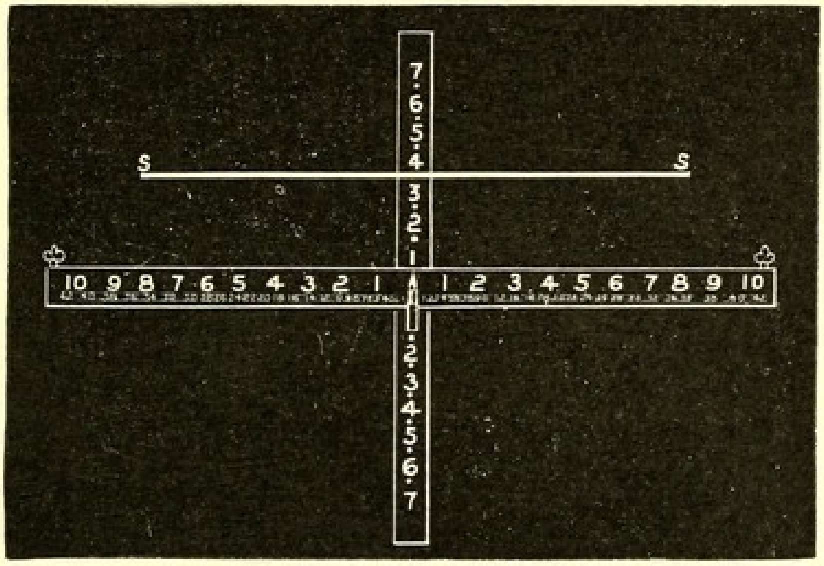


**Fig. 96**

**To illustrate the use of the author's Tangent Scales, the streak of light being represented by *S S*, which (if the patient be 5 m. distant) reveals $3\frac{1}{2}$° of hyperphoria in the naked eye. The naked eye sees the scales only ; the rod-clad eye sees the streak only**

its effect by contrast ; the apparent brilliancy thus attained is striking.

It is a good plan to have the horizontal and vertical scales, both in position at right angles to each other, with zeroes coinciding.

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* Those who use prism diopters can easily add small figures at intervals of 5 cm to the scale for their own perusal.

The horizontal element of a deviation should be recorded first, and then the vertical element.

**Previous Tangent Scales.**—Tangent scales for the measurement of strabismus were introduced by Landolt and Hirschberg about the same time (1875). Landolt's consisted of a tape marked at intervals of 5°, for extending along three walls of the consulting room, the patient standing at a point equally distant from the three. Another vertical tape extended from the floor to the ceiling, and along the floor also. This was an excellent plan, enabling, by a candle and a piece of glass, the squint to be measured with definite obliquities of vision. Hirschberg's would, perhaps, be better described as a tangent map, and served its purpose excellently as a strabismometer.* There is nothing new, therefore, in the tangent scale of Fig. 96, except the large and legible figure intended for the patient to read as well as the surgeon.

**Advantages of the Tangent Scale.**—When the patient has sufficient acuity of vision to read the large printed figures, on a scale affixed to the wall, this mode of measurement surpasses any other, since it is not only free from the fallacies of incorrectly-placed prisms, but it enables the patient to read off the amount of deviation from moment to moment, as it wavers or as it gradually increases or decreases, by which we gain some information as to the nature of the deviation.

This information is difficult to obtain if we dispense with the scale and only measure the deviation by the prism which annuls it.

Yet another, and perhaps the chief, point in favor of the scale is that it allows the surgeon to check the accuracy of the patient by observing whether the position of the streak is altered by a prism held before the patient's eye to the correct amount of its own deviating angle. Thus, if a deviation of + 3° be reported by the patient (*i. e.*, if the streak cross the black figure 3 on the same side of the flame as the eye before which the rods are held) a prism of, say, 8° deviation held before the naked eye, base out, would change the streak to the red figure 5. If the patient reports this truly, he can be trusted for the rest of the examination.†

It is, however, but rarely that such precautions are necessary,

* "Annales d'Oculistique," 1875; "Brit. Med. Journ.," Jan. 1, 1881.

† The rare and only fallacy in using a prism to shift the streak of light is that if the prism be too strong it may impair the visual acuity of the eye, before which it is held, enough to transfer fixation to the other eye. In most cases, even should this occur, the readings would be accurate; but in anisometropia or in paralytic muscular affections, the readings may be greater during fixation with one eye than during fixation with the other. Such conditions, however, are detected by their own appropriate tests.

and it generally suffices, if the patient be doubted, to transfer the disk from one eye to the other, to find if the streak is said to cross similar figures on opposite sides of the flame. It will be seen, therefore, that the glass rod is clear from the opprobrium of most subjective tests that they leave us at the mercy of the patient's statements.

The reason that figures to the right of the flame are black and those to the left red, is to give the patient a double mode of describing to which side of the candle the streak lies. I generally

(*a*) Ask which side of the flame the streak is : right or left? (If a child it is useful to touch its right or left hand or shoulder in company with the words.)

(*b*) What figure does it pass through?

(*c*) Is the figure black or red?

(*d*) If needful, transfer the rod to the other eye, and ask the same questions.

The same order applies to the vertical scale, substituting "above" and "below" for "right" and "left."

**Which Eye Fixes?**—It is sometimes a question whether the patient is fixing the flame or the streak. Though he cannot fix both at the same time, he is free to fix either, just as in Graefe's prism test, the patient can at will fix either the naked image or the prismatic one, either eye being able to move so as to receive an image on the fixing point of its retina, though the movement displaces the fixing point of the other eye away from its image.

If alternate fixation makes the streak shift to different figures, the case is one of either anisometropia or paresis. Alternate fixation can generally be secured by transferring the rods from one eye to the other, and so delicate a revealer of anisometropia is this procedure sometimes that so small a difference as .25 D. was once detected (before the refraction was tried) in a person with one eye Em., and the other H. = .25 D. Such cases show that the relation between accommodation and convergence, though very trainable is very delicate too.

**Other Uses of the Scale.**—Since multiplication of apparatus is undesirable, it may be said in passing that the same scale serves to measure the deviating angle of prisms, to measure squints, the angle $\gamma$, etc.

**Test for Concomitancy.**—Heterophorias should, in all cases, be tested in different parts of the motor field, to see if they are concomitant or paralytic. This is most easily done by repeating the test with the head held in different positions. To avoid confusion of mind, a good plan is to imagine the aerial screen of Fig. 74, to form a rigid system with the patient's face, so that when the face looks, for instance, down and to the left, the eyes looking straight forward, look through the right superior area. All that has been said heretofore about recording ordinary paralyses applies equally to paralytic latent deviations.

**Trial Test for Reliability.**—Before leaving the subject of the rod test, it may be well to remark that to secure full confidence in their use, tests for the eye should themselves first be tested, and nothing is easier than for the surgeon to test the reliability of the disk of rods for himself.

Selecting some correctly-marked prisms, stand precisely five meters from the tangent scales, with the disk of red rods before one eye and a green or blue glass before the other. If orthophoria exist, prisms held truly * in combination with colored glass before the other eye (or even without it) will make the red streak appear to pass through figures which correctly describe their deviating angles. It will be noticed, also, that however near the streak is to the flame, no tendency exists for them to run together.

**Heterophoria in Near Vision.**—For near vision the glass rod is not very suitable, on account of the difficulty of obtaining a sufficiently fine point of light. It is true that by utilizing a tiny electric lamp behind a hole in the cardboard, or the reflection from a minute silver button fastened in the middle of a tangent scale on a sheet of paper, and looking at this through a plano cylinder to economize all the light proceeding from it, a fairly good streak can be obtained ; but for clinical work I have abandoned this for my older small "tangent scale," published in 1884, and fixed just inside the cover of this book.

This scale is adapted for use at a quarter of a meter from the patient's eye and is graduated in degrees to the right and left of a central zero, the right hand figures being black and the left hand red. Meter angles, represented by $M^1$, $M^2$, $M^3$, $M^4$, are also marked on the scale. From the central zero projects a vertical arrow, and, at Mr. Berry's suggestion, I have placed a printed sentence just below the figures to ensure the patient's accommo-

* The way to hold a prism truly is to observe the image caused by double internal reflection, described in "Ophthalmological Prisms," 2d edition, p. 51, and which indicates the apex with unerring fidelity.

dation. The small figures are prism diopters for those who use that unit.

The scale can be triplicated by using a double prism, but the slightly greater accuracy thus secured is not so valuable as the saving of time effected by employing a single square prism of 6° deviation (about 12° old marking, or 10½^).

**Mode of Use.**—Holding the scale ¼ meter before the patient (about ten inches), place the square prism, edge up, before his right eye. He now sees two scales and two arrows. Being instructed to look at the *lower arrow* he is asked what figure it seems to shoot up at, also whether the figure is black or red, and as a control test he is asked what word in the printed sentence the arrow points to.

**Its Meaning.**—The surgeon, remembering that the lower arrow is seen by the left eye (since the image seen through the prism is displaced upwards in the direction of its apex) knows at once the nature and amount of any deviation, for if the lower arrow wander to the right, diplopia is crossed; and if to the left, it is homonymous, showing respectively, relative divergence and convergence. To save even this little calculation, however, "divergence" and "convergence" are marked on the scale.

**Physiological Exophoria.**—There is usually exophoria at ten inches of about one (binocular) meter angle, therefore 3° 40′; but it varies from 0° to 6° or 8°. Variations at this distance are not nearly so significant as in distant vision, unless esophoria is found to be present. It is difficult to fix an exact limit between the physiological and the pathological, and every case must be taken on its own merits, this test being only one of the many required to thoroughly examine a case.

**Prism Diopters in Near-Vision Tests.**—A fourth of a centimeter at 25 cm. distance represents one prism diopter, and it is quite easy to mark a card in this unit; but personally I prefer the old *degrees*, since it would be anomalous to measure manifest squints with one unit and latent squints with another. Degrees are converted into prism diopters when multiplied by 7 and divided by 4.

**Intermediate Scales.**—Though I have constructed scales for use at distances intermediate between 5 m. and ¼ m., they are not needed in practice.

**Tests for Breadth of Fusion.**—By breadth of fusion is meant the measure of the power of suppressing in the interests of single vision, artificially created diplopia.

In all cases of hyperphoria it is recommended by some to test the vertical breadth of fusion by finding both the strongest prism edge up and the strongest prism edge down, which can be held before the hyperphoric eye without causing insuperable diplopia. *Half* the difference between the prisms measures the true hyperphoria by this method, provided, of course, that the prisms are numerated according to their deviation. Thus, a sursumducent prism (*i.e.*, edge up) of 2° *d.* and a deorsumducent prism (*i. e.*, edge down) of ½° shows a hyperphoria of ¾°, with a vertical "breadth of fusion" of 2½°. Jackson's triple rotary prism is very suitable for this test.

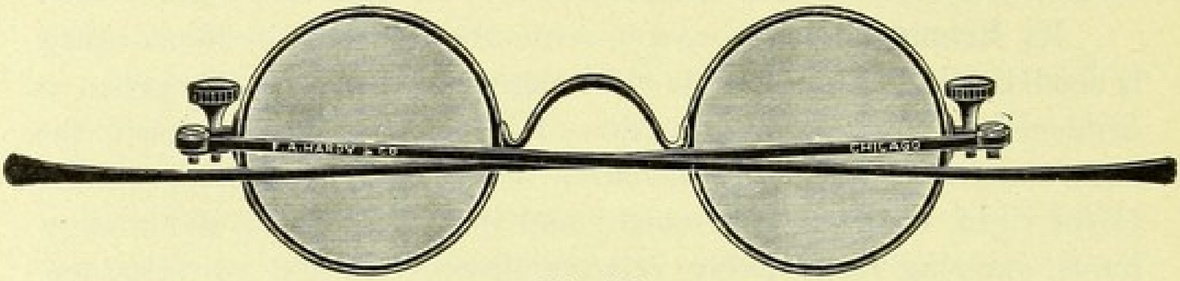


**Fig. 97**

A convenient Trial Frame, for the temporary and tentative use of prisms of American type

**Correction of Hyperphoria.**—In using relieving prisms or decentered lenses to correct hyperphoria, it is not well to correct quite the whole of it. A "relieving prism" should be placed, apex up, before the hyperphoric eye; or, if strong, it should be divided into two, one half being placed thus before the hyperphoric eye and the other half, apex down, before the descending eye.

Convex lenses should be decentered downwards before the hyperphoric eye and upwards before the other eye; concave lenses upwards before the hyperphoric eye and downwards before the other. The amount of decentering should be calculated as follows: Divide the number of required prism diopters by the number of diopters in the lens; this gives the decentering in centimeters. To express it algebraically—

$$d = \frac{\triangle}{D},$$

where $d$ is the decentering of *each* lens in centimeters, $D$ the dioptric strength of each lens in the vertical diameter, and $\triangle$ the number of prism diopters by which it is decided to relieve *each* eye.

**Relative Importance of Correction.**—The correction of persistent hyperphoria is far more desirable than that of any other form of heterophoria ; next in importance comes that of esophoria, and last that of exophoria.

**Concomitancy vs. Paresis.**—We do well to remind ourselves again in this connection that hyperphoria should always be tested with the face thrown in turn forwards and backwards to test for concomitancy on the one hand or paresis on the other : it is apt to be too much taken for granted that all hyperphoriæ are concomitant. If the diplopia increase on looking up or down, it should be tested in the nine motor areas, as described in the chapter on paralyses, and attention should be also paid to the torsion of the false image.

**The Horizontal Breadth of Fusion.**—This is measured by prisms with their apices in and out.

The power of overcoming crossed diplopia (produced by prisms apex in) constitutes the positive range of fusion, and the power of overcoming homonymous diplopia (produced by prisms apex out) constitutes the negative range of fusion.

A series of prisms, each stronger than the last, may be used ; or, better still, Crêtês', Risley's or Jackson's rotary prisms. They all, however, possess the disadvantage of having to be held before one eye and by impairing the distinctness of one image, leaving the other image naked, they tend to lessen the desire for single vision. Some such arrangement as that which I have designed and shown in Fig. 98 is better where two prisms have their apices,

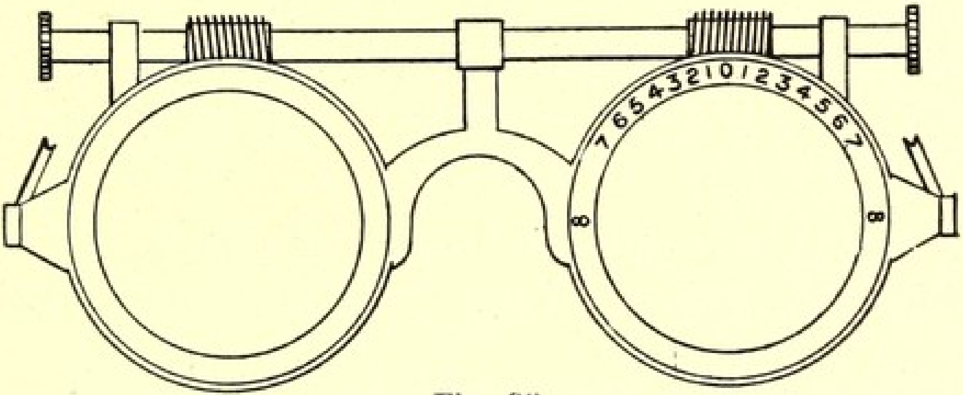


**Fig. 98**
Double Prismatic Trial Frame

to begin with, both up or both down, or both to one side, and are simultaneously rotated in opposite directions. The proportion between the positive and negative range differs according to the distance of the object looked at, the negative range being small in distant vision and greater in near vision.

**Orthoptic Training.**—Javal and others have shown how very much the horizontal relation between convergence and accommodation can be altered by systematic training, and when marked heterophoria is not relieved by the correction of refraction, I have come to believe it is far better to use training prisms than relieving ones. Instead of supplying the patient with a series of prisms increasing in strength, I now employ the frame of Fig. 97 and order one pair of strong prisms to be set therein. They can then be reset from time to time, so as to exert a stronger and stronger action. For example, with their apices down and in they would act as weak converging prisms and would be suitable to commence the training of an exophoria. At each visit the apices can each be rotated a little more up and in, so as to increase the amount of exercise. For esophoria the apices would be down and out in the same way. For hyperphoria, each apex can be directed to the right, but with one a little above the horizontal and the other below it. The prism that has its apex below the horizontal should be before the hyperphoric eye. When vertical and horizontal deviations occur together, it is quite easy to train them both simultaneously by adjustment of the prisms.

All training should be intermittent and be done at set times, when the eyes and the system generally are most free from fatigue.

Remember, it is conjugate innervations that are trained by prisms, and not muscles.

**Simple Rules for Heterophoria.**—The following, though too dogmatic for seniors, are suggested for the guidance of the inexperienced :

A—*Diagnosis.*

(1) Measure the deviation on the 5-m. scale by the disk of red rods before one eye and a piece of green glass before the other.

(2) Repeat the measurement with the head placed in different attitudes to ensure, by proving concomitancy, that no paralysis is present.

(3) Note the amplitude of convergence,* or at least the convergence near point.

(4) If the deviation be a horizontal one, test it also in near vision by small tangent scale and square prism.

*Refraction is assumed to have already been investigated.

(5) If time permit, test the breadth of fusion, or *prism duction*, as it is now called; especially the abduction power in esophoria, to see if it reach its normal limit of 4°, and the super and subduction in hyperphoria, to confirm the reality of the heterophoria.

B—*Treatment.*

(1) Remember that exophoria and cyclophoria in *near* vision are comparatively unimportant, and that in *distant* vision hyperphoria is at least four times more worthy of notice for each degree than horizontal deviations.

(2) If deviations cause no symptoms, leave them alone so far as special correction is concerned, yet do not ignore their evident indications, if glasses are needed otherwise, on the choice of these glasses. Thus, hypermetropes with esophoria should be fully corrected, since the relief of accommodation relaxes the convergence associated with it; hypermetropes with much exophoria should be under-corrected, and myopes with exophoria be fully corrected; presbyopes with esophoria in near vision need stronger lenses than those with exophoria, and so on (Norton and Savage).

(3) Deviations which cause some evident effort to overcome, with feeling of strain and perhaps occipital headache, require treatment. It is generally best to try simple correction of refraction first, decentering the lenses, if at all, only a little in the direction of relief. If that fail, orthoptic training, and if that also, operation.

(4) When all these prove insufficient, which should rarely be, so that heterophoria needs relieving prisms, I would suggest that:

Three-quarters of a persistent *hyperphoria* should be corrected by prisms or by decentering.

Two-thirds of a distant or the whole of a near *esophoria.*

Half or a third of a distant and a quarter of a near *exophoria.*

These rules, it need scarcely be said, are only a matter of general judgment, since each case needs its own study.

**Rules for Decentering.**—(*a*) Mentally halve the deviation, so as to divide its effect between the two eyes. (*b*) Decide what proportion of each half it is desirable to relieve (see last section). (*c*) Remember that a gradient or departure of 1° is approximately 1¾ in 100; therefore, since a lens of 1 D. has a focal length of one meter, it will have to be decentered 1¾ cm. to obtain 1° of deviating effect on light (see Fig. 99).

We can at once obtain the centimeters of decentering required for any given number of degrees if we

$$\frac{\text{Multiply the degrees by } 1\tfrac{3}{4}}{\text{and divide by } D.}$$

*D*, of course, being the number of diopters in the lens.

To put it in a formula (if *C* be the centimeters of decentering and *P* the desired prismatic effect) in degrees of variation,

$$C = \frac{7\,P}{4\,D}\text{; and } P = \tfrac{4}{7}\,C\,D.$$

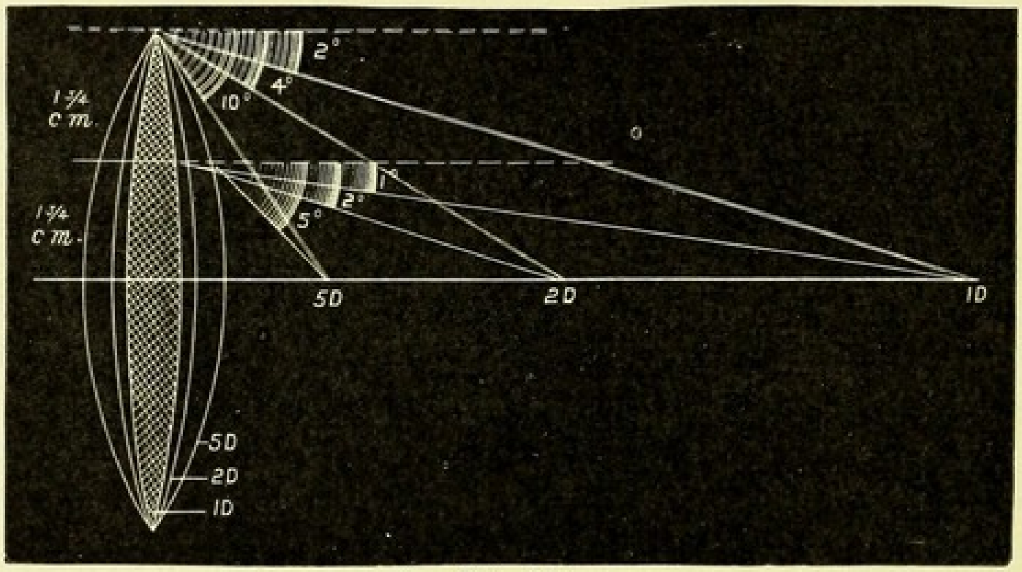


**Fig. 99**

To show the Prismatic Effect of decentering; each displacement of 1¾ cm. producing 1° deviation for each diopter in the lens. A meter lens will have its principal focus at *1 D*, so that light falling on the lens 1¾ cm. from its optical center is deflected 1°, another 1¾ cm. 2°, and so on. A half-meter lens will have its focus at *2 D*, and the corresponding deflections will be 2° and 4°. With a *5 D* lens they will be 5° and 10°.

**Prism Diopters.**—For those who use prism diopters the matter is simpler still, since we only divide the number of prism diopters required by the number of diopters in the lens to find the centimeters of decentration. The formulæ being

$$C = \frac{\triangle}{D}\text{; and } \triangle = C\,D.$$

**Direction of Decentering.**—Whatever the nature of the heterophoria, the following rules hold good:

Displace — lenses *with* the deviation.
Displace + lenses *against* it.

For example, in hyperphoria, before the highest eye
Decenter + lenses downwards.
Decenter — lenses upwards.

The rationale is very easy to understand, for every student knows that — lenses appear to displace objects *with* them, and + lenses *against* them. When an eye tends to deviate we displace the image in the same direction, so as to indulge the eye a little.

**Example.**—In a hypermetrope of 3 D., suppose we have decided to relieve a right hyperphoria of 4° by 1½° in each eye. Here

$$P = 1\tfrac{1}{2}^\circ \text{ and } D = 3,$$

$$\text{so that } C = \frac{7\,P}{4\,D} \text{ becomes}$$

$$C = \frac{7 \times 1\frac{1}{2}}{4 \times 3} = .875.$$

The right lens must be displaced *downwards*, therefore, 8¾ mm., and the left lens *upwards* to the same amount.

**Prism Diopters.***— Taking prism diopters —say we decide to relieve each eye by 2½△. Then

$$C = \frac{\triangle}{D} = \frac{2\frac{1}{2}}{3} = .83.$$

**Operative Interference** is indicated in :

(1) Diplopia, however occasional, which is too high for prisms, provided not due to any passing or removable cause or to progressive disease ; and if of sufficiently long-standing to give no hope of natural cure. The correction of any error of refraction should be tried first.

(2) Especially is the homonymous diplopia for distant objects experienced by some myopes (strabismus myopicus convergens) suitable for operation, since diverging effort is greater than converging ; yet we take care not to over-correct if in near vision there be already exophoria, since the diminution of the distant convergence is certain to be accompanied by a corresponding increase of the near divergence. Advancements alone are suitable.

(3) High esophoria, especially if it persists in near vision, is generally suitable for operation if correction of refraction fails ; but operation should only be considered if the suppressed squint cause subjective symptoms or conscious strain.

(4) Exophoria, or latent divergence, is generally of very little account at all, and only very rarely calls for operation. I have

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*A gradient, or departure, of 1 in 100 is a convenient unit and was chosen by Charles F. Prentice, M. E., of New York, as a unit of prismatic power, being called by Swan Burnett a "prism-diopter." "Centune" would, perhaps, be a better name for it when used for other purposes than prisms. It is a unit which does not bear multiplication, since its higher powers are not angular multiples of its lower.

seen some very high degrees, indeed, without suggesting it. When it causes periodic squint, or diplopia, after correction of refraction, the result of operating is generally excellent, provided a sufficient change of position is obtained. Improvement of the general health, bad teeth, or digestion, and errors of refraction need looking to first. In America large doses of tincture of nux vomica are recommended. Orthoptic training is suitable for those who will take the trouble. The amplitude of convergence should always be tested in these cases, and if it is good, operation is more likely to succeed.

The case on page 148 may be taken as one out of many to illustrate the necessity for an over-effect at first. It was that of a young school-girl with myopia = .5 ; .5, whose left eye turned outwards when tried. The tangent strabismometer showed the deviation to be one of — 20° L (the negative sign meaning divergence, and L the left eye). Under chloroform, both external recti were divided and one internus advanced, producing considerable convergence with homonymous diplopia, which, when measured a week after, was + 10° in the primary position. Three weeks after the operation it became O, and seven weeks after — 2°, where it seems to remain. The periodical "turning out" is cured and the eyes are rapidly regaining their concomitancy as measured by the rod test. There is no diplopia on looking in any direction.

(5) Hyperphoria, without occasional diplopia, is rarely large enough to be beyond the aid of prisms. When otherwise, and it causes distress, operation is quite justifiable.

When we want to produce a small effect, we have the choice of the following methods :

(1) Stevens tenotomy.

(2) DeWecker's capsular advancement.

(3) Knapps' or Savage's tendon shortening.

(4) Snellen's tenotomy with a limiting suture.

(5) Ordinary advancement without tenotomy of the antagonist.

These are described in all the better text-books, so that I need only mention here the convenience of using needles furnished with Hagedorn eyes and threads stained two or three different colors. For considerable advancements, where three sutures are used, the middle one should be attached strictly in the middle part of the tendon and catch in the sclerotic close to the cornea, where it is tied ;

*first*, the side sutures being ready to tie thereupon. The more the tendon is detached from the capsule and from its own conjunctiva, the safer the result.

**Graduated tenotomy** is another name for careful tenotomy. Partial "buttonholing" of the middle of a tendon has no effect unless a moral one, since the tendons are peculiarly inextensible, and even a narrow strand at each margin is enough to make the effect nil. But by dividing the tendon with great delicacy, so as to leave the indirect attachments unimpaired, an extremely small effect can be produced; and should it not be small enough, a limiting suture can be employed as well. The instruments introduced by Stevens for this purpose are admirably adapted for it, except that the hook and forceps are just a little too fine to do the best work, for the same reason that the finest catheter is not the easiest for strictures, being more apt to make a false passage.

**Marginal tenotomy** has been much advocated by Savage with a view to correct at the same time any cyclophoria. After "buttonholing" the tendon, as in Stevens' operation, one margin only is snipped with the scissors. The torsion of the eye is much less affected by this procedure in the case of the internal and external recti than in that of the superior and inferior, for obvious reasons.

## CHAPTER XIII

### Cyclophoria

Let us now consider this subject, at which Prof. Savage has worked so much. Cyclophoria is a tendency for the principal meridians of the retina to fall out of parallelism with each other whenever the eyes are disassociated, so as no longer to be engaged in ordinary binocular vision.

By far the commonest form is that in which the principal meridians diverge above (binocular extorsion). By tests made in near vision, Savage found it present in at least twenty-five per cent. of normal eyes. Cyclophoria of this kind has probably no clinical importance, unless it is very great or due to a paresis of an oblique muscle. In the latter case there will be vertical diplopia, either latent or manifest, down and to the opposite side from the paresed superior oblique. In the absence of any such tendency to vertical diplopia in the four corners of the field, as tested by the glass rod, cyclophoria must not be attributed to the oblique muscles, but to the innervations. Should need require, the slack innervation concerned may be strengthened by exercise, but, in nearly all cases, non-paralytic cyclophoria causes no symptoms and requires no treatment.

**Its Detection and Clinical Measurement.**—When a disk of mounted rods is held before one eye of a patient who is engaged in looking at a distant flame, it sometimes happens that while the rods are horizontal the streak of light created by them appears more or less sloping, and to make it vertical the rods have to be tilted from the horizontal.

Such a patient has latent torsion or cyclophoria. If the amount be considerable and the diameters of the disk be truly marked, the degree of torsion can easily be read off from an astigmatic trial frame.

**Its Exact Measurement.**—For very accurate work, the rods would be better mounted, exactly horizontal,* in a rigid stand, with a long thin wand pivoted to the wall behind the flame, or a

*Optical adjustment is superior to the use of a spirit level. It can be effected by adjusting the rods so as to obtain the maximum definition of a thin vertical line on the wall.

cord so fastened by one end as to be adjustable to the vertical, or to any inclination from it. The tilting of the wand or slanting of the cord required to bring either parallel to the streak of light, represents the cyclophoria. Since, for clinical purposes, however, such accuracy is not necessary, simple rotation of the disk of rods in the trial frame till the streak appears parallel with a fixed vertical or horizontal line on the wall is quite sufficient. Cyclophorias are divided into "paretic" and "non-paretic."

**Paretic Cyclophoria.**—Whenever leaning of an image is observed to any marked extent, the possibility of slight paresis of one of the obliques should not be overlooked, and measures should be taken accordingly to discover whether the tilting varies on looking in certain directions ; also whether, on looking up and down, any inconcomitant hyperphoria can be demonstrated by the rods.

**Non-paretic Cyclophoria.**—Tilting which is not paretic is due to slackness of one of the conjugate innervations. It will be remembered that there are three or four of such innervations connected with torsion—one causing parallel dextrotorsion, another parallel lævotorsion, another conjugate intorsion, and yet another (perhaps) conjugate extorsion.

**Explanation of Leaning Image.**—It may be well to explain the relation between the tilting of the streak of light and the torsion of the eye.

When a flame is fixed with both eyes without any apparatus, a vertical line inscribed on the wall, passing through the flame, throws its image on the vertical meridian of each retina, these vertical meridians being kept parallel to each other by torsional innervation, in order to combine the two pictures into one.

As soon, however, as a glass rod is placed before one eye, all active innervation exerted in the interest of single vision ceases and the eye rolls into its position of dissociation.

While the glass rod is horizontal the picture formed by it upon the retina remains geometrically vertical and, therefore, now, as soon as torsion occurs, this linear picture falls on a new meridian of the retina which is not the originally-vertical one, and is projected according to the rule that the false image is displaced in the opposite direction to the displacement of the eye. A dextrotorted streak, therefore, means a lævotorted eye, and *vice versa*.

As soon as the rod is tilted so as to make the retinal picture fall on the originally-vertical meridian of the eye, the streak appears vertical.*

**Rule for Rod Test.**—This very simple rule, therefore, may be made that the torsion of the rod, required to make the streak appear vertical, represents exactly the torsion of the eye, both in sense and amount.

**Cyclophoria in Near Vision.**—Dr. Savage, of Nashville, has worked much at the subject of latent torsion in near vision by a test of his own, for which he utilized the author's double prism of Fig. 91.

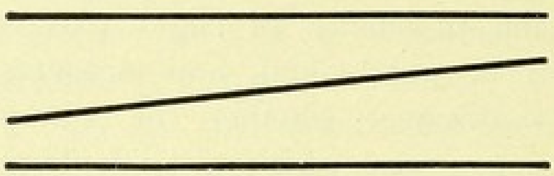

Fig. 100

Dextrotorsion of the naked eye, causing apparent lævotorsion of the middle linear image

On looking at a card marked with a horizontal line, through the double prism held before one eye, the patient sees two parallel false images of the line and a third real image (Fig. 100) between them, which slopes with respect to the other two in a sense opposite to the torsion of the eye that sees it.

Dr. Savage attempted to cure it by exercising the eyes in the opposite direction, using a weak cylindrical lens for the purpose, rotation of which tilts the image of a vertical object seen through it. For exercises in distant vision, Duane's suggestion is a good one—to use two disks of glass rods, one for each eye, and gradually rotate them in opposite directions while endeavoring to keep the streak of light from doubling ; thus, with the bi-prism before the left eye, the appearance is generally as in Fig. 100, showing excyclophoria. This condition is so common as to deserve being regarded as physiological. For near vision, a steroscope such as suggested by Perry, or Javal's "stéréoscope à cinque mouvements," could be used ; or, perhaps best of all, Helmholtz's rotating prisms, which enable an object to appear gradually rotated ; but the author does not think that cyclophoria which appears in near vision only, needs treatment at all.

**Oblique Astigmatism.**—When an eye with oblique astigmatism looks at a vertical line, the image of that line on the retina is twisted from the vertical towards the meridian of maximum corneal curvature. The image thrown from a horizontal line is likewise

* For physiological experiments I have devised a more delicate test, in which any tendency to fusion is more entirely abrogated (*Ophthalmic Review*, June, 1894), but not being a clinical test, it has no place here.

twisted, also towards the same corneal meridian. To verify these facts let the reader look at a cross line, as in *a*, Fig. 100½, with the right eye, after having placed before it a strong minus cylinder with the axis down and in. The appearance is as shown in *b*, Fig. 100½, each arm of the cross being twisted toward the axis of the cylinder. A similar cylinder with its axis down and in before the left eye, the right being shut, would give the appearance of *c*, Fig. 100½.

It is evident that were no rotation of the globes about the lines of fixation permissible, the effect with both cylinders together

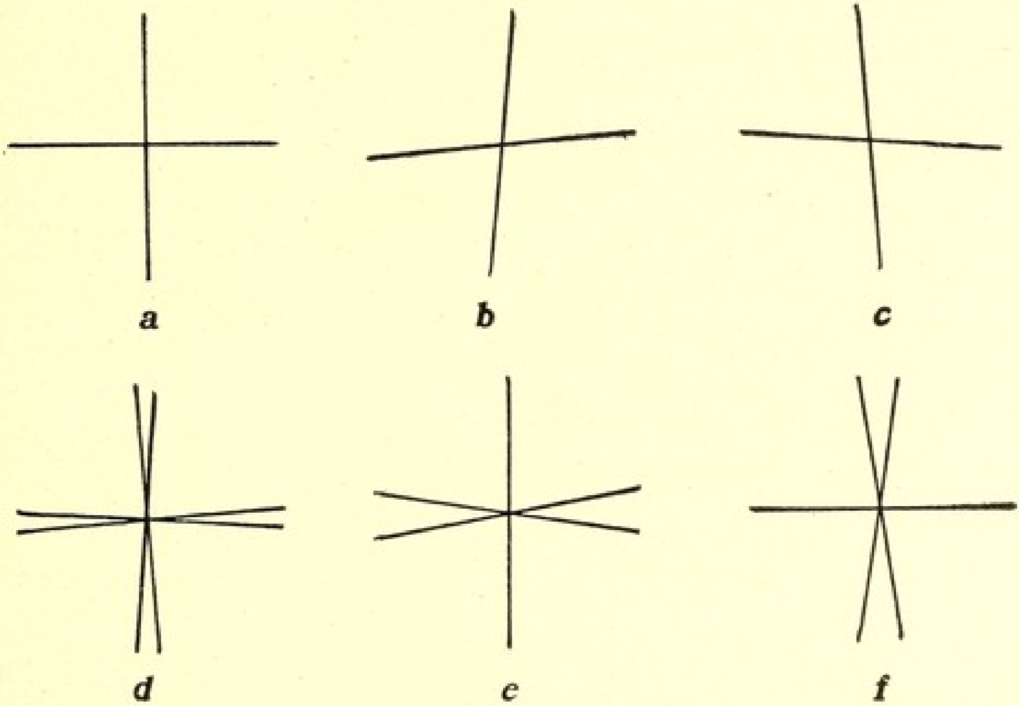

Fig. 100½

would be as in *d*, Fig. 100½. What really occurs, however, is that both eyes become either extorted or intorted, according as we confine our attention to the vertical line or the horizontal one.

At *e*, Fig. 100½, is shown the appearance when the vertical line is attracting most attention, its double images being fused in consequence of binocular extorsion of the eyes, which allows each image to fall on the principal meridian of its retina ; by this very act the angular separation betwen the horizontal images becomes doubled. In *f*, Fig. 100½, the horizontal line has attracted attention and its double images have been brought together by binocular intorsion, which has doubled the angular separation between the vertical images.

This constant alternation of the adjustment of the eyes about their fixation lines is, no doubt, what accounts for the greater frequency of headaches in oblique astigmatism as compared with other kinds, nor can it be corrected in any other way than by the correction of the astigmatism.

Too exclusive attention to the horizontal images, together with the supposition the whole picture of an object is tilted on the retina in the same direction as its horizontal lines, has led some to suppose that the correction of certain kinds of astigmatism throws strain on the superior obliques and that of other kinds on the inferior obliques. But the above simple treatment of the subject shows that the correction of oblique astigmatism relieves both pairs of obliques; or, to put it more correctly, gives less work to the two innervations which govern binocular extorsion and intorsion.

Since Savage called attention to the effect of the correction of oblique astigmatism, the subject has attracted attention. If an oblique cylinder be held before a normal eye, a square figure looks drawn out or shrunken in a direction perpendicular to the axis of the cylinder, according as the latter is convex or concave, so as to illustrate the fact that both vertical and horizontal lines are tilted, *against* the axis of a convex, and *with* the axis of a concave cylinder, when its axis is oblique. Were this all, every side of the square would appear double or, at least, indistinct; but the mind prefers to see two sides clearly, even though at the expense of the other two, and this desired end is attained by either conjugate intorsion or extorsion of the eyes, according to taste. Horizontal lines in near vision are preferred generally to be seen distinctly at the expense of the vertical. In an astigmatic eye this state of matters is permanent, and the corrective torsion is a life-habit. When, therefore, oblique cylinders are prescribed, this life-habit has no longer any *raison d' être*, and ceases. Whether in selecting the best axis for the cylinder, we do well to take account, as Savage suggests, of the altered torsional conditions, is very questionable.

It should be remembered that latent torsion is much more common in near vision than in distant vision, and when it exists in both, is apt to be the greater, being in fact to a certain extent physiological, and, I believe, analogous in its own spheres to the exophoria so generally found in near vision, in the domain of the converging innervation.

**Cyclophorometers.**—Several instruments of this name have been invented for the measurement of cyclophoria at a distance rather than in near vision. The first to be published was that of Price, who placed mounted glass rods vertically before both eyes, with, in addition, a double prism, ridge horizontal, before one eye. Similar instruments followed, with some improvement of detail by Baxter, and Brewer, and others; some with single prism and others with double, and all excellently planned. When a point of light is looked at through these instruments one eye sees its horizontal line of light inclined with respect to the line or lines seen by

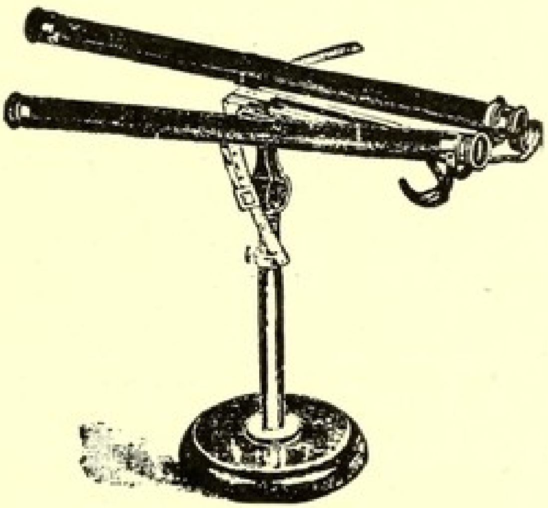

**Fig. 101**
Optomyometer of the Geneva Optical Company

the other eye when cyclophoria is present, and the measurement is effected by rotating one disk in a graduated arc till the lines are all parallel.

Two more forms of apparatus for latent torsion deserve description.

**Optomyometer.**—The first is the "optomyometer" of the Geneva Optical Company, shown in Fig. 101. It consists essentially of two tubes, nearly twenty inches long, one of which is capable of horizontal movement only, while the other can be elevated or depressed to any required angle. The patient is made to look, with both eyes, down these tubes, and sees a thin slit cut in a rotating disk at the far end of each. By a little adjustment of the movable tube its own slit can be made to appear vertically above the other, and then if one slants with reference to the other, the disk is rotated till the slant is corrected. If the patient have any latent torsion, it will be found that when the slits appear to him to have the same direction, they actually are inclined to or from each other to an extent which exactly measures his latent deviation. In a variation of the experiment, one slit can be made

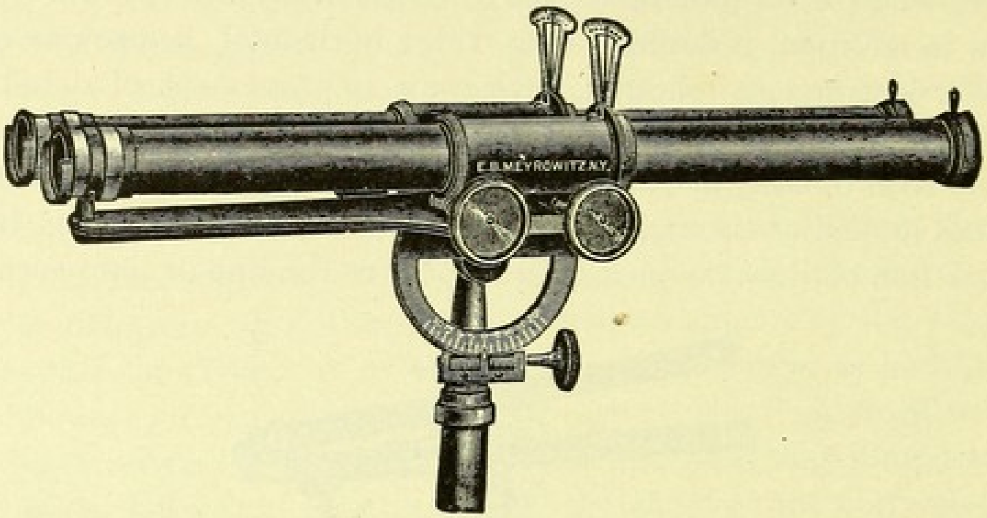


**Fig. 102**

Stevens' Clinoscope

to appear to the patient to lie across the other one at right angles to it; when if a latent torsional deviation be present, the slits will be found to be really inclined to each other by a greater or less angle than 90°.

**Clinoscope.**—Dr. Stevens has improved on this instrument, in his clinoscope, which consists of two tubes nearly twenty inches long, mounted on a brass platform. The attachment to the platform permits the tubes to be adjusted in parallelism, in convergence or in divergence, and the platform itself is attached by a movable joint to an upright standard, so that the tubes can be given any desired dip simultaneously. The tubes can be rotated about their longitudinal axes by thumb-screws, and this motion is recorded by an index-pointer above each tube. At the far end of each tube provision is made for maintaining diagrams in position. An example of these figures is shown in Fig. 103, which represents two pins, one to be seen by each eye.* The heads of the pins blend, and by rotating one till the pins form a continuous straight line, the latent torsion is measured.

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* **Volkmann's Apparatus.**—A design similar to this appears, according to the language of Helmholtz, to have been that employed by Volkmann: "Instead of a whole diameter on his rotary disks, he only traced one radius, and endeavored on binocular examination to make these radii appear in the same straight line. The head was suitably held: the rotary disks were placed in two darkened tubes which could be directed at will by the aid of suitable joints, so that each eye should see one disk through each of the tubes, the disk remaining always perpendicular to the line of fixation."

To measure the amplitude of torsion, similar disks are used, but with a complete diameter, instead of a radius (Fig. 104), on each. These diameters are fused, and by rotating both in opposite directions till they begin to separate the strength of the faculty of fusion is measured.

Dr. Stevens finds the amplitude of extorsion for each eye to be 11° and that of intorsion to be slightly less. This holds good when both eyes are simultaneously extorted or simultaneously intorted.

He finds, however, that he cannot, while maintaining the vertical position of one of the lines in the clinoscope, rotate the other to an extent double of that to which the two were rotated. With one line vertical he can only slant the other to right or left by about 14°, without breaking fusion.

Curiously enough, he says that horizontal lines are not held in fusion nearly so easily as vertical ones, the amplitude for each eye being only 3° inwards and 3° outwards.

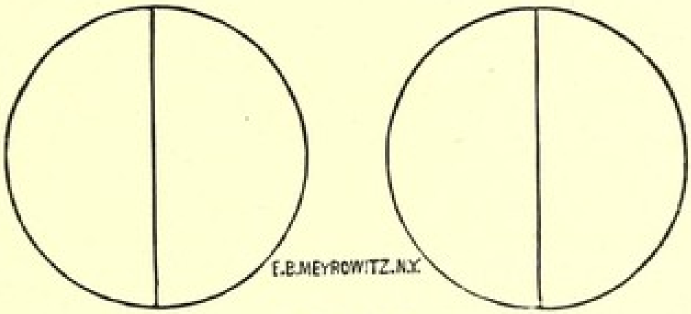


**Fig. 103**

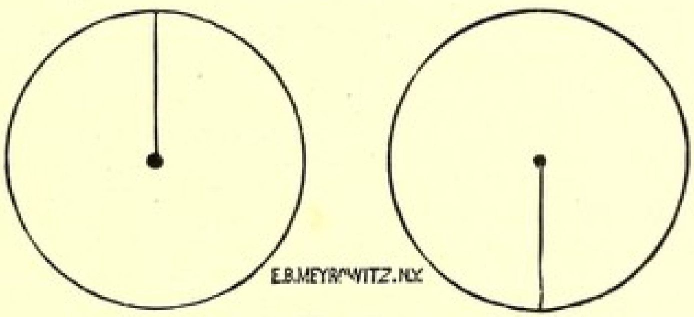

**Fig. 104**

He says that during artificial binocular extorsion or intorsion the united line appears concave or convex, according to the will of the observer.

**Meissner's Test, 1858.**—It is only for convenience that Meissner's test is included in this chapter, since the phenomena of torsion manifested by it are not strictly those of "latent" torsion, but of physiological actual torsion during single binocular vision for near objects. This is apt to be confused with latent torsion, to which, indeed, it is closely related.

It appears that in ordinary binocular vision of near objects both eyes rotate outwards about their optic axes (binocular extorsion), and the more so the nearer the object becomes.

This species of torsion increases when the visual plane is elevated and lessens as it is depressed, till it at last disappears

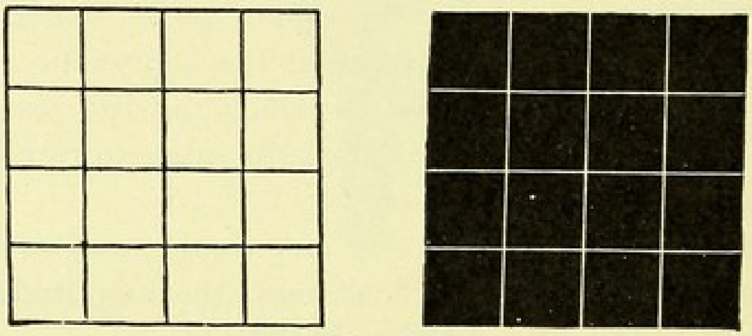

**Fig. 105**
Haploscopic Figures slightly inclined (Le Conte)

altogether, when the fixation lines are depressed 45° below the horizontal; if depressed more than that, intorsion of both eyes is apt to show itself.

Meissner proved these points by taking a metallic thread, stretching it perpendicularly to the plane of fixation and looking at it in such a way as to make the visual lines converge to a point situated a little beyond or a little behind this thread. He found the double images of the thread not parallel but relatively intorted, showing that the eyes are, to the same degree, extorted. By moving the lower end of the thread nearer the observer and the top farther away, so as to introduce an element of perspective (the top of the thread being now farther from the eyes than the bottom) the double images can be made parallel. The amount of the previous intorsion of the images can easily be calculated from the amount of inclination required to be given to the thread to bring the double images to parallelism.

Le Conte has carefully confirmed Meissner's results, differing in one point only, namely, that while the latter believed that a greater inclination must be given to the thread as vision becomes nearer, Le Conte finds, with his own eyes at least, an inclination of 7° or 8° to be that required for all near distances.

**Depression of the Visual Plane.**—Meissner found that the more the visual plane and the thread were simultaneously depressed (the mid-point of the thread being kept at a uniform distance from the eyes all the time), the less the thread had to be displaced from the perpendicular to the visual plane, till, with a depression of 45° it needed no displacement at all. In this position of the eyes, therefore, the torsion we are considering becomes nil. Helmholtz calls this the "primary position of the eyes for convergence," defining primary position as that of zero torsion (Nullpunkt der Raddrehungen), and stating that in convergence the eyes have a lower primary position than when the visual axes are parallel. In his own case he found zero lie one day a little higher and another day a little lower, and even to become altered during a series of experiments. It is useless, therefore, to attempt too great a precision in denoting it.

**True Primary Position in Distant and in Near Vision.**—In distant vision, Helmholtz defined the primary position for the parallel motions of the eyes as that in departing from which, in any cardinal direction, no false torsion was generated. During convergence he also tested the deviations from Listing's law in the secondary positions of the eyes, and found them to be such as to confirm the idea of the primary position in convergence being one of depressed visual axes.

**Le Conte's Confirmation.**—Le Conte's experiments showed that, with the point of fixation at the following distances from the root of the nose the torsion was shown in this little table :

| | | | | | | |
|---|---|---|---|---|---|---|
| At 7 inches—each | eye | became | extorted | | | 1¼° |
| " 4 " | " | " | " | " | | 2½° |
| " 2.2 " | " | " | " | " | | 5° |
| " ¼ " | " | " | " | " | | 10° |

On looking up, *i. e.*, with elevation of the visual plane, the extorsion increases, which Le Conte attributes, no doubt truly, to the inferior obliques ; on looking down, as already described, it becomes less.

**Savage's Test Compared.**—All this shows that in making Prof. Savage's test with the double prism, note should be taken both of the distance at which the test is made and of the inclination of the head, for though his test is not the same as Meissner's, since the two eyes are thoroughly dissociated (whereas, in Meissner's they are not dissociated at all), there is no doubt the results *include* the phenomena here treated of. His test is doubtless a good one in its place, but its value should be carefully differentiated. For example, when torsional defects are apparent in distant vision to any marked degree, it is of service to *also* investigate the conditions in near vision to see if they present any great departure from what Meissner showed to be physiological.

As already confessed that in the clinical study of latent torsion, I do not attach much significance to near vision phenomena, unless coupled with distant vision defects ; but it is perhaps well not to overlook the possibility of rare cases in which Savage's and Meissner's tests might show great anomalies.

**Eaton's Apparatus.**—Perhaps the best rough clinical way to institute Meissner's test is that suggested by Eaton of a strip of

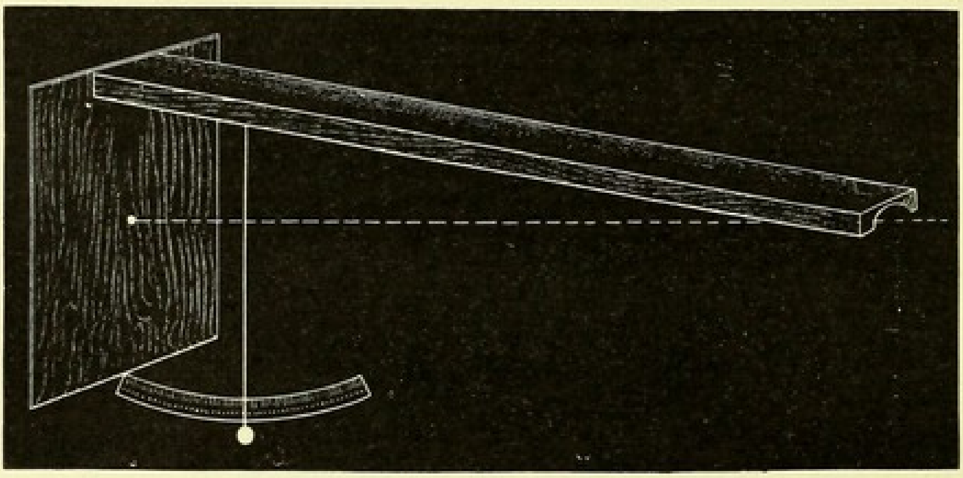

**Fig. 106**
Eaton's mode of making Meissner's Test

wood grooved at one end to rest on the root of the nose, with a white metal plate rigidly fixed to the other extremity so as to hang down therefrom at such an angle as to be perpendicular to the visual plane, when a black dot in its middle is fixed by the patient. A long hat pin, with its head downwards, is stuck by its point into the under part of the strip of wood an inch or two from the end and parallel to the metal plate.* This is shown in Fig. 106.

To use the apparatus : First depress the whole till the images of the hat pin become parallel ; this discovers the amount of depression which must be imparted to the visual axes to obtain zero torsion. Secondly, by making the patient look straight forward,

* A graduated arc might with advantage be arranged to indicate the inclination of the pin, as shown in the figure.

the hat pin can be slanted so as to bring its head nearer the patient till parallelism of the double images is obtained—the amount of slant showing the amount of extorsion. Lastly, by elevating the apparatus the increase of the torsion on looking up can be demonstrated.

Much more elaborate and accurate apparatus could be devised, but for clinical purposes they might induce us to make much of little. I have made the following simple rule, which affords a sufficiently close approximation for clinical work: Multiply the number of degrees by which Meissner's thread has to be inclined to make the images parallel, by half the interocular distance in centimeters (generally about 3.2) and divide by the distance of the center of the thread in centimeters; this gives the torsion of *each* eye in degrees.

**Formula for Meissner's Test.**—The formula I obtained, where $I$ is the inclination of the thread in degrees, $T$ the torsion of each eye and $C$ the angle of convergence for each eye, is:

$$\text{Tan. } T = \text{Tan. } I \text{ Sin. } C.$$

Putting arcs as equivalent to tangents, the formula becomes:

$$T = I \text{ Sin. } C.$$

From which we see: (1) That for any fixed distance of the thread the torsion of the eye increases proportionately to the inclination of the thread, and (2) that for any given and constant inclination of the thread the torsion varies with the sine of the convergence.

Thus, with the thread 50 cm. (about 20 inches) away, the torsion of each eye would be .064 of the inclination of the thread; at 25 cm. (about 10 inches) it would be twice as much, namely, .128; at 20 cm. (about 8 inches) .16; at 15 cm. (about 6 inches) .21; at 10 cm. (about 4 inches) .32; and so on.

It only remains to show how to arrive at the formula.

**How Formula Obtained.**—Let us, for convenience, call that meridian of each retina which is vertical while both eyes look straightforwards at distant objects, the originally vertical meridian, and that plane which passes through it, as well as through the point of fixation, the originally vertical plane.

During distant straightforward vision the originally vertical planes of the two eyes are parallel, since both are vertical, and they intersect each other in a vertical line passing through the point of fixation.

Were the eyes to experience no torsion during the act of convergence, this line of common section would still remain vertical for every distance of fixation. But any torsion of the eyes is, of course, accompanied by equal rotatations of their originally vertical planes about their axes of fixation, and though the originally vertical planes must still intersect one another in a straight line passing through the point of fixation, that line remains no longer vertical, but has its upper end inclined towards the observer, if the case be one of intorsion, and away from the observer if the case be one of extorsion.*

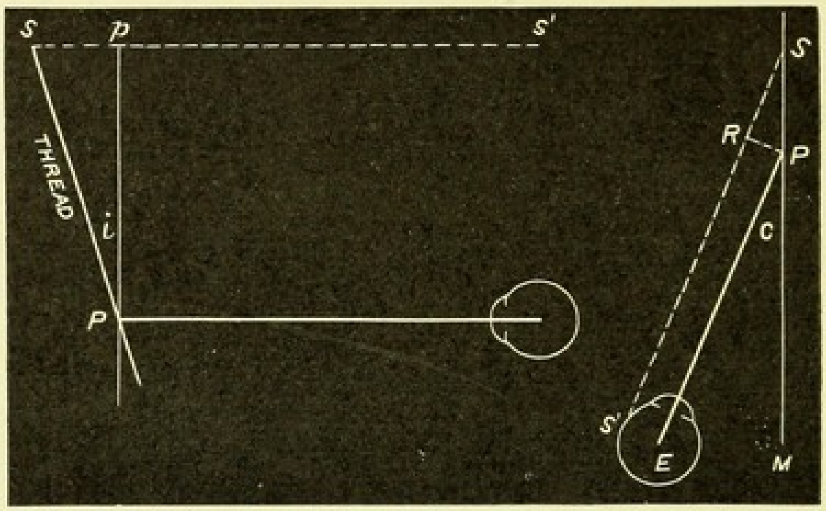


**Fig. 107** **Fig. 108**

Author's plan of solving Meissner-Torsion

The greater the rotation of the originally vertical planes, during any constant distance of fixation, the greater is the tilt backwards or forwards of their line of common section.

On the other hand, to produce a constant tilt of the line, greater torsion is needed for every increase of convergence.

Now, it is only when Meissner's thread is held parallel to this line of common section of the originally vertical planes, that its images appear parallel to one another. Given the distance of fixation, we learn at once from the inclination which we have to give to Meissner's thread what is the rotation of the originally vertical planes, and thus the torsion of the eyes.

Fig. 108 gives a horizontal plan of the problem, $E\ P$ being the left axis of fixation, meeting the median plane ($M\ P$) at the point of fixation $P$, so that $C$ is the angle of convergence for the left eye.

The left originally vertical plane passes through the axis of fixation $E\ P$ and rotates about it in strict association with the torsion of the eyeball, thus intersecting the median plane in a straight line, which ever passes through $P$, either perpendicularly to the plane of the paper (as when no torsion exists) or with more or less inclination from the perpendicular (according to the torsion).

Select in the originally vertical plane an imaginary line running parallel to the axis of fixation, and at any unit-distance from it. So long as the originally vertical plane is vertical this line will lie immediately over the axis of fixation and, in the horizontal plan of our figure, appear to coincide with it. If the eye be extorted, however, the line will occupy some such position

*The reader to whom this is not self-evident, may think of the prow of a canoe.

as that shown in plan by $S S'$, meeting the median plane at $S$ (which we may regard as the upper extremity of Meissner's thread, when the middle of the thread is fixed by the eyes at $P$).

Now, designating the angle of torsion by $T$, the ordinary rule of horizontal projection gives us

$$R\,P = \text{Sin. } T,$$

and it is evident, from the figures, that

$$P\,S = \frac{R\,P}{\text{Sin. } C} = \frac{\text{Sin. } T}{\text{Sin. } C}. \qquad (1)$$

But $P\,S$ equals the horizontal co-ordinate of the upper half of Meissner's thread, shown in side elevation in Fig. 107, as $p\,S$. Whence—

Since $P\,p$ was, by construction, taken as unity,

$$p\,S = \text{Tan. } i.$$

Therefore, from (1)

$$\text{Tan. } i = \frac{\text{Tan. } T}{\text{Sin. } C}.$$

and

$$\text{Tan. } T = \text{Tan. } i \ \ \text{Sin. } C.$$

Which means approximately that *the torsion of each eye is directly proportional to the inclination of the thread*, and *also* to the *amount of convergence in true meter angles.* True meter angles are found by measuring the distance of the point of fixation from the center of the eye, and finding how many times that distance will go into a meter.

Most readers will agree that this subject is a difficult one.

## CHAPTER XIV

# The Eye in Darkness

The problem now before us* is to discover how an eye behaves when it is covered by the hand, or otherwise placed in total darkness, while its fellow is still actively engaged in near vision.

We have already seen that, during deep sleep, the eyes generally experience exotropia, as proved by simple inspection. But when awake in darkness it is clear that, except for more pronounced deviations than those which occur physiologically, we cannot solve this difficult problem by direct inspection of the eye or through Javal's ground glass; neither can after-images afford us any assistance, since movements resulting from alterations of the convergence innervation are just those which after-images do not betray.

Even, therefore, if we were to gaze steadily at a source of light till it became impressed on the retina before darkening the eye with the hand, the eye might then move under the hand without any apparent movement of the after-image.

What is needed is an apparatus capable of placing an eye subjectively in absolute darkness, and yet able to take account of its movements. To solve this problem by utilizing the blind spot I devised the visual camera in 1882. It need hardly be recalled that the blind spot (or "punctum cæcum," discovered by Mariotte) is an approximately circular gap in the field of vision of each eye, which was shown by Donders to be due to the fact that the entire surface of the optic disk is wholly insensible to light. There is an area, therefore, in the field of vision of each eye which is entirely devoid of visual impressions and large enough, according to Helmholtz, for eleven full moons to stand in a row in it. The center of the blind area lies about 15° to the outside of the point of fixation, and its diameter subtends an angle of about 6°.

The "camera" consists of a light wooden box, represented in Fig. 109, blackened inside, and of a somewhat wedge-like or pyramidal shape, its dimensions being about a foot from side to side and about nine inches from before backwards. It is one inch deep along the curved border and inclines gradually to the depth of

* Trans. Oph. Soc., 1882-3, and Jour. of Anat. and Phys., vols. xx and xxi.

half an inch at the narrow end. The latter is provided with two visual apertures pierced through slides *a a* which permit of mutual approximation or the reverse, and between them is a groove for the nose. A fixed median partition *b* extends to within two inches of the middle of the curved border and is crossed by a small transverse "obstructive" *c*, which is merely a little piece of wood suspended through a slit in the roof, in which it can slide from side to side. The curved end of the box is built up of two arcs *d d*, each described about the center of motion of its corresponding eye and united by a straight piece 64 mm. long, in the center of which is a tiny *fixed* aperture *e* covered by thin paper, bearing a printed letter so as to ensure accurate accommodation. On either side of this arc are two movable apertures *f f*, preferably colored red and green respectively, and pierced through brass slides *s s*, which travel so that each luminous point can be moved at pleasure along its own half of the curved end independently of the other. This is made possible by a system of long slits, so cut in the brasswork that the luminous points can be made to travel without admitting any adventitious light, since the slits mutually overlap each other. The brass slides are marked in degrees, which indicate the angular distance of each luminous point from the central aperture.

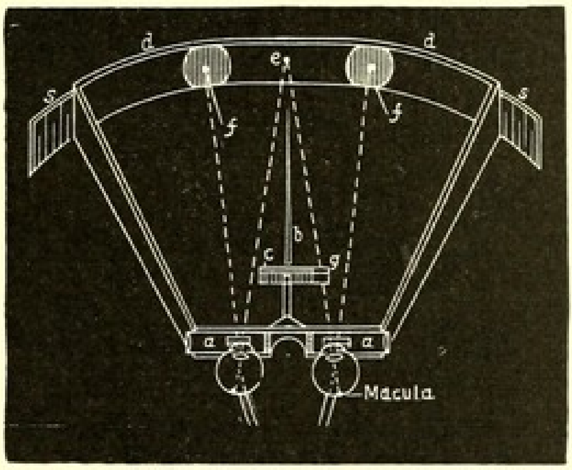


**Fig. 109**
**The Visual Camera**

To make our first experiment, adjust the two lateral apertures *f f* so that each shall be 15° distant from the central aperture *e*, and place the obstructive in the middle of its path as represented by the shading *c*. Now look into the camera, holding it so as to let the light fall on the three small apertures *f e f* but for which its interior is quite dark, and gaze at the printed letter in the central aperture *e*; while doing so the two lateral apertures *f f* will be invisible, since they fall on the blind spot of each eye, and are lost to view. The circles of shading which are represented in the figure surrounding the apertures *f f* correspond to the two blind spots and are at that distance about an inch in diameter.

Now suddenly push the obstructive to the right, into the position shown by *g* in the figure. The mind remains quite unconscious that the vision of the fixation aperture *e* by the right eye is cut off by this action, though the aperture appears a little dimmer. Now, however, the right eye is subjectively in absolute darkness, since the left luminous point *f* is hidden by the median partition *b*, the central fixation aperture *e* is hidden by the obstructive *g* and the right lumiuous point *f* is lost in the blind area.*

The fixation aperture *e*, however, begins at once to appear moving slowly towards the right, and in a few moments the luminous point *f* springs into view, showing that the eye has been moving sufficiently for its blind area to no longer contain the luminous aperture, and the two visible apertures appear nearer to each other than they really are. If we attempt to touch each of them separately, by a finger outside the box, the average of a number of attempts would show that the right-hand aperture *f* appears displaced a little to the left of its true position, and the fixation aperture appears displaced a little to the right of its true position.

Now withdraw the right-hand luminous point outwards, till it is again lost to view in the blind area; it will remain lost, showing that the eye, having moved outwards a certain extent, remains there. It is easy to localize the inner border of the blind area before and after the push given to the obstructive, and thus to measure in degrees the amount of deviation suffered by the eye. The amount varies in different persons; in some it is nil, but on the average nearly 4° of outward deviation takes place.

In the following table, which collects the results obtained from ten different persons, the average amount of deviation is a little too high to be representative. It shows, however, how greatly the amount of deviation varies in different individuals. The first two columns show what is the angular interval between the inner and outer borders, respectively, of the blind area and the visual axis, the difference between which gives, of course, the angular dimensions of the blind area.

In my own case the deviation varies from 3° to 7° or even 8°, according to the time of day, the state of health, the previous occupation of the eyes and, I think, also the temporary compara-

* In fact, the only illumination of the right eye is gathered into a tiny image $\frac{1}{400}$ of an inch wide in the center of the optic disk.

tive anæmia or congestion of the brain. It appears to be greater in the morning than in the evening, and less after much reading, especially when the head is congested from close application or hot rooms.

TABLE I

| No. | Inner border of blind area | Outer border of blind aera | Breadth of blind area | DEVIATION |
|---|---|---|---|---|
| 1 | 12½° | 18¼° | 5¾° | 0° |
| 2 | 12½° | 18½° | 6° | 1° or ½° |
| 3 | 12½° | 19° | 6½° | 2½° |
| 4 | 11° | 17° | 6° | 4° |
| 5 | 12½° | 18½° | 6° | 4½° |
| 6 | 12½° | 18½° | 6° | 5° |
| 7 | 13° | 19° | 6° | 6½° |
| 8 | 13° | 18½° | 5½° | 7° |
| 9 | 11½° | 17° | 5½° | 7° |
| 10 | 12½° | 18½° | 6° | 7½° |
| | | | Average . . . . . . | 4½° |

The physiological experiments which can be made with this camera are too numerous to be all treated here.

**Sense of Projection.**—Fig. 110 shows one in which two tiny apertures, each seen by only one eye, when separated a certain distance, appear superimposed. This distance measures the exophoria for the distance of the base of the camera, and by asking the patient to touch the superimposed apertures, his sense of projection can be tested.

**Effect of Attention on the Desire for Fusion.**—An instructive experiment consists in making the two eyes see one image double, while a third image is seen by one eye only. If attention is fixed upon this third image, though there is nothing to prevent the diplopia from being overcome, there is found to be no desire to overcome it, even though, by the nature of the experiment, the double images are perfectly focused, being in the same plane as the third one on which the attention is fixed. But the moment attention is paid to either of the double images, they instantly run together. This experiment throws much light on the relation between attention and the desire for single vision.

To make the necessary arrangement of the camera, the right lateral aperture is placed two degrees to the *right* of the central one, the former being filled in or covered with a piece of paper marked with a printed letter, and the latter covered with tissue paper, and therefore blank. On looking into the camera, with the "stop" in the middle, the two points are seen in their true position, the printed letter appearing to the right of the blank aperture. Now push the "stop" to the right; the two images begin to move slowly together till superimposed, and continue this movement till they have just changed places. The lettered aperture is now about 2° to the *left* of the blank one. While attentively examining the letter, replace the "stop" in the middle; immediately another blank image appears to the left of the lettered one, so that the letter has now one blank image on each side of it and at equal distance from it, and this arrangement remains so long as the letter receives chief attention, but the moment either blank image is looked at, it and its fellow run together, the letter returning to its true and original projection to the right. This illustrates many points in the laws of conjugation.

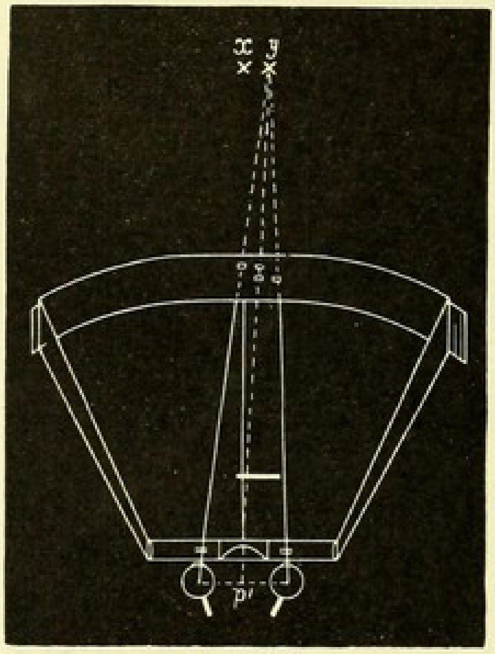

**Fig. 110**
The Camera used to test Projection

**Speed of the Exophoria.**—The *rate* of relaxation of convergence can be measured by timing, from a pendulum, the movements of a "stop." It begins with me in less than half a second and goes on with decreasing speed, which becomes inappreciable after from half a minute to a minute and a half.

**Laws of Conjugation Illustrated.**—Several more experiments can be made to illustrate these on the principles mentioned in Chapter V, showing that the oculo-motor muscular sense is purely central, the same contraction of a muscle being mentally appreciated in one way or another according entirely to the innervation in play. Such phenomena as the following are very evident with my own eyes.

When one eye is excluded the object fixed by the seeing eye appears to move in the same direction as the deviation of the covered eye, but at half the rate and through half the angle.

Thus a fixed object, watched by a stationary eye may appear to move, though in another experiment the same fixed object seen by a moving eye may appear stationary. It all depends on what conjugate innervations are in play.

An image on the fovea, whatever be the real position of the object it belongs to, appears in my case to be referred to the plane which bisects the angle of convergence, and which therefore passes through the point of fixation and a point midway between, and slightly behind, the centers of the two eyes. This plane is shown by *y p'* in Fig. 110 and *c b* in Fig. 33.

In spite of exophoria, the nervous connection between convergence and accommodation is most sensitive, since the slightest increase of the latter is accompanied by an approximation of the double images.

**False Fusion.**—When two apertures are arranged for each to be seen by only one eye, the desire to unite them increases in proportion to their apparent nearness, and may be greater than the desire to unite true double images, if the separation of the latter from each other be greater. By making their heights different, the images tend to keep as near as they can to the same vertical line, even if they cannot overcome the vertical separation ; but this tendency ceases if the difference in height be more than 2° or 3°.

**Diluted Fusion.**—By moving the "stop" from the center of its path to one or other end of its path, at measured brief intervals, the vision of a single aperture can be made alternately monocular and binocular. The monocular intervals favor exophoria, while the binocular intervals tend to prevent it. By regulating the intervals, exophoria may at pleasure either be prevented or allowed to go on at any slower rate than normal, or be arrested and maintained at any part of its course, or be made to slowly decrease. The desire for single vision is lessened, or diluted, as it were, by monocular intervals.

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# THE OPTICIAN'S MANUAL

## VOL. II.

**By C. H. Brown, M. D.**

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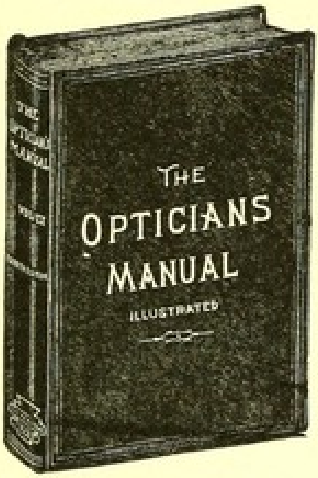


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