THE OCULAR CONJUGATE AND FUSION
BRAIN CENTERSONLY TWO AXES OF OCULAR ROTATIONS, AND ONLY TWO
PLANES OF REFERENCE *

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In my investigations, some years ago, I saw the importance of finding a larger number of brain centers for the control of the ocular muscles than had been given in any list of these centers published up to that time. I not only found that there must be conjugate centers whose existence had never been announced, but that there must also be fusion centers. To the old list of conjugate centers I added six additional members; the sixth, the seventh, the eighth, the ninth, the tenth and the eleventh. The first, second, third, fourth and fifth conjugate centers had already been recognized, and Maddox had said "probably more." In addition to the six conjugate centers added to the original number, I found that there must be a fusion center for every individual extrinsic muscle, and also an individual center for each ciliary muscle and for each sphincter of the iris. In this paper I shall not refer again to the individual centers for each ciliary muscle and each sphincter of the iris, or to their conjugate centers; but only to the conjugate and individual centers pertaining to the extrinsic ocular muscles, nine of the former and twelve of the latter. I named the first eight of these fusion centers, right and left first basal centers, right and left second basal centers, right and left third basal centers, and right and left fourth basal centers. Notwithstanding it had been previously published that there was a fifth conjugate center, I found no evidence of the existence of right and left fifth basal centers, hence the skip from fourth to sixth. The remaining four I named right and left sixth and right and left seventh basal centers. To all of these basal centers, thus enumerated, I gave the general name of fusion centers, and declared them to be under the control of the fusion faculty of the mind. The purpose of this paper is to prove the existence of the nine conjugate centers connected with the extrinsic muscles of the eye, and the twelve fusion centers connected with these muscles. All of these are shown in Figure 1.

I did not recognize at that time that all ocular rotations, whether monocular or binocular, were effected around only two axes. At that time it was a matter of general knowledge that rotations in the horizontal plane were around a vertical fixed axis, and that the vertical rotations were around a horizontal fixed axis. I, at that time, found myself in agreement with the teaching of those who had preceded me, that every oblique rotation was around a fixed axis and that this axis was at right angles to the rotation plane; but this is not true.

In Figure 2 I represent the equator of the eye and the vertical and transverse axes lying in the plane of the equator, and I unhesitatingly declare that around these two axes are effected all oblique rotations, and that throughout such a rotation each of these two axes is itself in motion; there are no fixed axes for oblique rotations.

I was not alone in the thought that an oblique point in the upper field might be reached by a rotation, first around the vertical axis and then upward on the trans-

verse axis of the eye, without any torsion of the eye on reaching the obliquely placed second point of view. I was at that time, as I am now, convinced that in oblique rotations there was no torsion and I concluded that the torsioning did not occur because of the contraction of the obliques for the purpose of preventing it. I still believe, and shall prove, in connection with the study of Figure 3, that oblique secondary points of view are reached without torsion, and that this is prevented by the obliques.

A few weeks ago the thought occurred to me that, if two simple rotations, the first around the vertical axis and the second around the transverse axis, could enable the eye to reach the second point of view obliquely placed, without torsioning, the same muscles could effect the rotation in an oblique plane by acting simultaneously on the eye, one rectus effecting the upward or downward and the other rectus the right or left movement, while an oblique stands guard against torsion.

I at once appealed to my muscle indicator for proof of the correctness of the thought. I saw at once that, while the elevators were rotating the eyes on their horizontal axes, the lateral recti could rotate the eyes at the same moment around the vertical axes, and that the result of this double rotation taking place simultaneously would be the same as if the eyes had moved first around one of these axes and then around the other. I elevated the isogonal circle of the muscle indicator, carrying the visual axes with it, but at the same time, by another force, I shifted the axes in the plane of the isogonal circle and reached a secondary point of view without torsioning. The two forces were independent of each other, and yet were acting in most perfect harmony. Thus it is that I shall be able to prove, as I proceed, that every oblique rotation is effected by the conjoined work of three conjugate centers and two fusion centers, the five acting on three pairs of muscles; that one of these pairs elevates or depresses the two eyes, another pair shifts the visual axes to the right or left, as the case may be, and the third pair prevents any rotation around the visual axes; that one fusion center acts on one lateral rectus, hindered by an oblique, while the other fusion center acts, as the case may be, on one superior or one inferior rectus, hindered by an oblique.

That the study of Figure 3, in proof of the existence of all of the nerve centers named above, may be made easier, I shall group the twelve ocular muscles into the nine pairs, and in connection with each pair, shall name the conjugate center in control.

1. The two superior recti, under the control of the first conjugate center, for elevating the visual axes.
2. The two inferior recti, under the control of the second conjugate center, for depressing the visual axes.
3. The two interni, under the control of the third conjugate center, for the converging of the visual axes.
4. The right externus and the left internus, under control of the fourth conjugate center, for effecting rotations to the right.
5. The left externus and the right internus, under control of the fifth conjugate center, for effecting rotations to the left.
6. The two superior obliques, under the control of the sixth conjugate center, called into action only when the rotation is directly down and in conjunction with the second conjugate center and the two inferior recti, the purpose being to prevent outward torsioning.
7. The two inferior obliques, under control of the seventh conjugate center, but called into action only when the rotation is directly up, and then in association with the first conjugate center and the superior recti, the purpose being to prevent torsioning inward.

* Read in the Section on Ophthalmology of the American Medical Association, at the Sixty-Second Annual Session, held at Los Angeles, June, 1911.

8. The superior oblique of the right eye and the inferior oblique of the left eye, under control of the eighth conjugate center and called into action only when rotations are obliquely up and to the right or down and to the left, to prevent torsioning to the right.

9. The superior oblique of the left eye and the inferior oblique of the right eye, under control of the ninth conjugate center, called into action only when the rotation is up and to the left, or down and to the right, to prevent torsioning to the left.

As to the fusion or basal centers, which could also be called the duction centers, the following is true:

The right and left first fusion centers belong, respectively, to the right and left superior recti. The right and left second fusion centers belong, respectively, to the

which represents the vertical fixed plane of the head. These two planes, at right angles to each other, have their line of intersection in *e-f*. Points in space located anywhere on this line are primary points of view, and are known to be on this line of intersection. The plane *a-b-c-d* is a plane of reference so far as objects above or below it are concerned. The plane *g-h-i-j* is a plane of reference for all objects either to the right or left of this plane.

If *f* be the point of fixation and the lateral recti muscles are normal, only the third conjugate center has acted and only the two interni have responded. If the eyes are esophoric, to prevent the visual axes crossing between *e* and *f*, the right and left fourth basal centers must each act on its individual externus. If the eyes are exophoric, the right and left third basal centers must be called into action to prevent the crossing of the visual

Fig. 1.—Conjugate and fusion brain centers.

right and left inferior recti. The right and left third fusion centers belong, respectively, to the right and left interni. The right and left fourth fusion centers belong, respectively, to the right and left externi. The right and left sixth fusion centers belong, respectively, to the right and left superior obliques. The right and left seventh fusion centers belong, respectively, to the right and left inferior obliques.

Having named all of the conjugate and fusion centers and the pairs of muscles, or individual muscles, to which they respectively belong, it now remains for me to prove, by means of Figure 3, the actual existence of all these. The two planes to which I wish to call special attention are the plane *a-b-c-d*, which represents the horizontal fixed plane of the head extended; and the plane *g-h-i-j*,

Fig. 2.—The equator and the two axes of rotations.

Fig. 3.—The two planes of reference.

axes at some point beyond *f*. The neuricity from the right and left third basal centers has supplemented the neuricity from the third conjugate center.

If the eyes are to be rotated from *f* to *f''*, and are orthophoric, the third conjugate center will keep up the convergence and the fourth conjugate center alone, acting on the right externus and the left internus, will sweep the point of convergence from *f* to *f''*. If the eyes are esophoric the neuricity to the left internus would make the eye move faster and farther than the right externus would move its eye, if there were no supplementary supply for the latter muscle. This supplementary neuricity would come from the right fourth fusion center. If the eyes were exophoric, the neuricity from the fourth conjugate center would make the right eye

move faster and farther than would the left, unless supplemental neuricity should be sent to the left internus. This supplemental power would come from the left third basal center.

If the eyes were to be rotated from f to f' , and they are orthophoric, the convergence would be kept up by the third conjugate center, and the point of fixation would be carried from f to f' by neuricity from the fifth conjugate center only, acting equally on the left externus and the right internus. If the eyes to be thus rotated are esophoric, the neuricity from the fifth conjugate center to the right internus would make the right eye move further and faster than that sent to the left externus would turn the left eye. To prevent this lagging behind of the left eye, supplemental neuricity must come from the left fourth fusion center to the left externus. If such eyes were exophoric, the right eye would lag behind the left, unless supplemental neuricity should come from the right third basal center.

If the rotation is to be from f to z , the visual axes must be lifted by the two superior recti, and the vertical axes must be kept parallel by simultaneous action on the part of the inferior obliques. The impulse to the former muscle would come from the first conjugate center, and that to the latter would come from the seventh conjugate center. If the eyes to be thus rotated are orthophoric, no basal center would be called into action, but if the left eye should be hyperphoric, the neuricity from the first conjugate center would make that eye move upward faster than the right eye would go, unless the superior rectus of the right eye should receive supplemental neuricity from the right first basal center. Reversing the hyperphoria, the neuricity would have to come from the left first basal center in order to make that eye sweep in harmony with its fellow.

Rotations of these eyes from f to z' , if orthophoric, would be effected by neuricity from the second conjugate center, acting on the two inferior recti to pull the visual axes down, and, simultaneously, neuricity would come from the sixth conjugate center to the two superior obliques, and no basal center would be aroused into activity. But, if the right eye be cataphoric, supplemental neuricity would have to be sent from the left second basal center to the inferior rectus of the left eye, in order to make it keep pace with its fellow in rotation. In either of these vertical rotations the convergence would be effected by the third conjugate center.

In any rotation above the horizontal plane, whether cardinal or oblique, the first conjugate center must be active. In any rotation below the horizontal plane the second conjugate center must be active. In any rotation to the right of the vertical plane, whether in the horizontal plane or above or below it, the fourth conjugate center must be active. In any rotation to the left of the vertical plane, whether in, above or below the horizontal plane, the fifth conjugate center must be active. In a cardinal rotation above the horizontal plane, the two inferior obliques must act together. In a cardinal rotation below the horizontal plane, the two superior obliques must act together. In oblique rotations up and to the right and down and to the left, the eighth conjugate center must act on the superior oblique of the right eye and the inferior oblique of the left. In any oblique rotation up and to the left or down and to the right, the ninth conjugate center must act on the left superior and the right inferior obliques. These oblique rotations, even of orthophoric eyes, cannot take place under the influence of the conjugate centers alone, for the reason

that one oblique will help one of the recti muscles of a pair and hinder the other, and *vice versa*, of each eye, thus making it necessary for one basal center for a rectus muscle belonging to one eye to be active to overcome the retarding influence of the oblique muscle, and the same is true of the retarded rectus muscle of the other eye. To illustrate: In the oblique rotation up and to the right, the right superior oblique would help the right externus, but would hinder the right superior rectus. The inferior oblique of the left eye would hinder the left internus, but would help the left superior rectus. The right first basal center, therefore, must help to stimulate the right superior rectus, and the left third basal center must help stimulate the left internus. The basal center for the oblique muscles counteract the insufficiency of these muscles, whether the eyes be at rest or in motion.

Without the fusion centers, duction would be impossible; therefore, they can very properly be called duction centers. Each of the right and left first basal centers would produce superduction. Each of the right and left second basal centers would produce subduction. The right and left third basal centers would produce adduction. The right and left fourth basal centers would produce abduction. The right and left sixth basal centers produce minus cycloduction and the right and left seventh basal centers produce plus cycloduction.

The conjugate centers are verting and converging centers, and are not the centers that stand guard when oblique rotations and heterophoric conditions would cause the visual axes and the horizontal retinal meridians to leave the plane of the primary isogonal circle.

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ABSTRACT OF DISCUSSION

DR. MELVILLE BLACK, Denver: We have listened to Dr. Savage for a good many years and he has told us many valuable truths. Once we get his ideas straightened out a little they are not at all difficult to follow. I believe we are greatly indebted to Dr. Savage for having attacked a theory of Helmholtz that seemed incontrovertible. I believe he has shown that Helmholtz was mistaken in certain of his teachings, and that it should be for a member of our Section to have positively demonstrated this fact is worthy of our commendation.

DR. HIRAM WOODS, Baltimore: Back as far as C. S. Bull's edition of Sollberg-Wells' text book there is an excellent discussion of the individual action of each eye muscle, together with the position in which the individual action of that muscle will put the eye, and how that position will affect binocular vision, and how some of the results of that individual action are compensated for or removed by other muscles. For instance, it is stated that in convergence the interni work together on the primary horizontal plane. In lateral motion the externus of one eye and the internus of the other act on the horizontal plane. In looking directly up the superior rectus pulls up and tilts the vertical meridian of the cornea inward, and that tilting is removed by the contraction of the inferior oblique. In looking down, on account of its oblique insertion, the inferior recti pull the eye down, tilting the vertical meridian of the cornea out, and the superior oblique overcomes that. Now with the exception of the introduction of these hypothetical centers and the term "cardinal rotation," wherein is Dr. Savage's teaching different from that taught us twenty-five years ago? Wells worked it out from the action of each individual muscle. Dr. Savage works out the identical thing and seems to me to assume these association centers. No one esteems Dr. Savage more than I for his scientific worth, but I cannot see that we are any further ahead in the understanding of muscular action for the assumption of these centers.

DR. G. C. SAVAGE, Nashville: This instrument, the muscle indicator, is built on the fundamental truth that the center of the macula is the posterior pole of the eye, and that the visual axis and all other visual lines go through the center of rotation. My faith in that proposition has been backed by me financially and otherwise. I offered, two years ago, a thousand dollars to any man who would name a single phase of an ocular muscle or any combination of ocular muscles, normal, abnormal or pathologic, that I could not show with this device. That the center of the macula is the posterior pole and that lines of direction are radii of retinal curvature prolonged, and that the judgment of the scientific world will be that at no very distant day, I have not the slightest doubt. I am sorry that there was not some discussion relative to the motions of the eye. I do not take it as an indication that there is nobody here who understands this part of physiologic optics. I am sure very many here do understand it, but I think they are willing for me to continue the fight in a lone-handed way until the victory finally comes. [The remainder of the discussion was a demonstration of the existence of the twelve fusion brain-centers, each connected with only a single ocular muscle, as set forth in the body of the paper.]

CHANGES OCCURRING IN THE REFRACTION OF CORRECTED AMETROPIC EYES *

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In undertaking this analysis of cases of ametropia, in which the error had been determined one or more times after the lapse of several years from the time of the first determination, and in which correcting glasses had been worn, I was actuated by a desire to see whether some unformulated belief which I possessed, and which I had nowhere seen expressed, would be borne out by facts. Further, as so little is said in text-books on ophthalmology and on refraction, and as some of the things which are said are not in accord with my unsubstantiated views I wished to clear my mind of the uncertainty. Quotations from some of the standard text-books and from the writing of several authorities will here be given that a comparison may be made between the views there expressed and conclusions reached as the result of this analysis. A perusal of the chapter on refraction in text-books on ophthalmology and of special treatises on refraction shows that with one or two exceptions the subject is entirely ignored.

The possibility of an eye with low hyperopic astigmatism becoming myopic was conclusively shown more than twenty years ago by Dr. William F. Norris and also by Dr. Samuel D. Risley. Dr. Risley laid particular stress on the rôle played by astigmatism in bringing about this change. As he expressed it: "without exception they passed from the too shallow hypermetropic eye-ball, over into the lengthened myopic eye, through the turnstile of astigmatism." This fact is so generally recognized as not to require confirmation at this time, yet many text-books make no mention of it. The "hypermetropia acquisita" of Donders is the only supposed change in the refraction of the eye of which note is generally taken. MacNamara, quoted by Randall, urges that young hyperopes, even those with absolute hyperopia, should not be given correcting glasses or even under-correcting lenses for constant wear, asserting that the normal development of the eye, whereby the hyperopia would be outgrown, might thus be interfered with,

and the defect rendered permanent. Randall, having had the same thought, and having acted on it, did not observe a decrease in the hyperopia in a single instance. Nettleship states that hyperopia always dates from birth and does not afterward increase, except slightly in old age; but it may diminish and give place to myopia by elongation of the eye.

Jackson sees in the occurrence of astigmatism in 41.8 per cent. of myopes and only 17.2 per cent. of hyperopes, a connection between astigmatism and myopia. He further states that there is little reason to doubt the correctness of the common belief that the majority of cases of astigmatism remain the same throughout life. He records eighteen cases of progressive hyperopic astigmatism. In all, there was an increase in the degree of the hyperopic astigmatism. He is of the opinion that the frequency of these cases would be about 2 per cent. of all cases seeking relief on account of anomalies of refraction. The cases in which, after the lapse of an equal length of time, the use of a mydriatic has shown no change in the amount of the astigmatism outnumbered them very decidedly, and cases of mixed and myopic astigmatism are relatively, though not absolutely, more frequently progressive. He has encountered no case of regressive astigmatism—none in which the astigmatism had diminished so much as $\frac{1}{2}$ D., though it is not improbable that such cases occur. In most of the cases there was an increase in the hyperopia in all of the meridians. In six of the cases there was actual diminution of the hyperopia in one of the principal meridians of one or both eyes. He has not found that the liability to change in the amount of astigmatism is confined to any one particular period of life, though such changes may be more frequent in early life.

Emerson also reported a case of progressive hyperopic astigmatism.

Theobald has recorded a case in which there occurred an increase of hyperopia with an increase of astigmatism, a case of increase of myopia with an increase of astigmatism, and a case of myopic astigmatism becoming mixed astigmatism. He believes such cases to be probably of infrequent occurrence. Randall doubts the occurrence of hyperopia acquisita of advanced life in the sense referred to by Donder.

According to Thorington, astigmatism may develop from any disease or injury that will cause a lengthening, shortening, or inequality in one or more of the meridians of the cornea or lens. The same author refers to the development of compound myopic astigmatism from low degrees of compound hyperopic astigmatism and in this connection states that it is well known that hyperopic astigmatism is a congenital defect.

Alger refers to the development of myopia from hyperopia and also the acquired hyperopia of old age.

Duane is the only author whose writings contain any extended reference to the phase of refraction with which this paper has in particular to do. Regarding astigmatism, he says: "Once developed, it remains, on the whole, practically stationary during childhood, youth and early manhood. Changes do take place in it from time to time, but they are inconstant and usually slight, and there is no special rule governing the way in which they develop. After middle life, however, there is a tendency for astigmatism to change its character. Astigmatism with the rule tends to become less, or is sometimes converted into astigmatism against the rule, and astigmatism against the rule often develops where no astigmatism existed before, so that in old age astigmatism against the rule is the most common variety."

* Read in the Section on Ophthalmology of the American Medical Association, at the Sixty-Second Annual Session, held at Los Angeles, June, 1911.