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Physiological Studies on Pupillary Reaction

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Abstract

1. The excitability of the different parts of the retina for the Pupillary reflex movement was examined with Hess's differential pupilloscope. 2. The consensual reaction is observed in man, cats, and dogs, but found neither in those animals whose optic fibres decussate perfectly in the chiasma, -for example, guinea-pig, nor in those animals which have non-decussate fibres not running to the superior colliculus, - for example, rabbits, rats, and goats. 3. The so-called Gudden's pupillary fibres are identical with the optic fibres themselves, but their nerve fibres are nothing but the special optic fibres which run to the superior colliculus. 4. The pupillary movement does not attend to the accommodation of the eye itself, but convergence of the visual axes. 5. A new scheme of the nervous connection for the pupillary reflex movement which explains all facts known without contradiction is advanced by the author.

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Physiological Studies on Pupillary Reaction.*

By

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1. On the excitability of the different parts of the retina for the pupillary reflex movement.

Schirmer considered that the peripheral receptive organs which cause pupillary movement are amacrine cells, but this hypothesis was denied by *E. V. Hippel* who showed that amacrine cells do not exist in the fovea centralis where the pupillary reflex movement is most effective. Since then many investigations on the peripheral receptive organs for that reflex have been undertaken by many investigators. *C. Hess* also investigated the pupillary reflex movement from the retina by light and came to the conclusion that the excitable district for that reflex is much narrower than the retinal area excitable for the red and green light and that is 4 mm. in diameter at most. According to *Koster*, the retinal area devoid of rods is 0.8 mm. in diameter, but *Landolt's* datum differs somewhat, i. e. the diameter of the fovea centralis is 0.2-0.4 mm.; the distance between the fovea centralis and the center of papilla nervi optici is 3.915 mm. and the diameter of the macula lutea is 2 mm.. Only man and monkeys have the macula lutea, and in other mammals the part is called as the area centralis. Birds, especially hawks, wild ducks, and sea-gulls have two yellow spots.

Experimental: The excitability of the different parts of the retina

* This thesis was presented at the Physiological Congress in Japan, 1925.

for the pupillomotor-reflex was examined with *Hess's* differential pupillo-scope, by which the minimum strength (in fraction of the arbitrary unit) of light capable of causing pupillary reflex was determined. Supposing that the eye of the examinee is the reduced eye, the distance between the fovea centralis and the center of the retinal image is easily calculated.

Experiment I. The bright adaptation of eye.

Table 1.

Diameter of a retinal image	Distance between the fovea centralis and the center of the retinal image.	Quotient of <i>Hess's</i> pupillo-scope.
0.76—0.74 mm.	0.0 mm.	0.302
◇	1.1	0.087
◇	3.4	0.053
◇	4.3	0.035
◇	5.2	0.029—0.032
◇	6.0	0.032
◇	7.0	0.026

In case of the bright adaptation the excitability for the pupillo-motor-reflex rapidly decreases, as is shown in Table 1, as the illuminated part shifts towards the peripheral parts of the retina from the fovea centralis.

For instance, when an image of 0.75 mm. in diameter is made, the center being set on a point 5.2 mm. from the fovea centralis, the quotient of *Hess's* pupillo-scope is about 1/10, compared with that of the image is cast on the fovea centralis.

Experiment II. The dark adaptation of eye.

Table 2.

Diameter of a retinal image.	Distance between the fovea centralis and the center of the retinal image.	Quotient of <i>Hess's</i> pupillo-scope.
0.76—0.74 mm.	0.00 mm.	0.490
◇	0.86	0.278
◇	1.10	0.278
◇	2.20	0.237
◇	4.30	0.237
◇	5.20	0.237
◇	7.00	0.257
◇	7.60	0.219

On the contrary, in a case of the dark adaptation, the degree of decrease in the excitability for the pupillo-motor-reflex from the peripheral parts of the retina is very slow as is shown in Table 2.

The distance of the excited spot of the retina from the macula was calculated by using the following ratio, i. e. 10° of the visual angle corresponding to 2.7 mm. on the retina.

Experiment III. The difference of excitability.

Then the difference of excitability from the outer and the mesial halves of the retina under the condition of comparatively dark adaptation was examined and found that in both cases the excitability decreases as the illuminated point shifts toward the peripheral parts from the center of the retina, and the degree of decrease is almost the same in both cases, as shown in Table 3 and 4.

Table 3.

Outer half of the retina.		
Diameter of a retinal image.	Distance between the fovea centralis and the center of the retinal image.	Quotient of <i>Hess's</i> pupilloscope.
0.53—0.52 mm.	0.000 mm.	0.257
◇	0.493	0.158
◇	1.590	0.145
◇	2.380	0.145—0.158
◇	3.180	0.133
◇	3.980	0.133
◇	4.770	0.122
◇	5.570	0.112

Table 4.

Mesial half of the retina.		
Diameter of a retinal image.	Distance between the fovea centralis and the center of the retinal image.	Quotient of <i>Hess's</i> pupilloscope.
0.53—0.52 mm.	0.000 mm.	0.257
◇	0.495	0.158
◇	1.590	0.145
◇	2.380	0.122
◇	3.680	0.122
◇	3.980	0.112
◇	4.770	0.122
◇	5.570	0.095

Experiment IV. Experiment with red and white light.

Then using both red and white electric lamps, lighted by two volts accumulator, the author measured an extent of the field of vision and of a part that causes pupillary movement only in the upper and the lower part of the retina by fixing the visual lines of the examinee upon the center of *Foerster's* perimeter with both eyes open. The results are shown in Table 5.

Table 5.

Condition of adaptation.	Kinds of light of electric lamps.	Part that causes pupillary movement.	Field of binocular vision for white or red electric light.
Relative bright adaptation.	red	30°	70°
Relative dark adaptation.	white	30°	76°
Relative dark adaptation.	red	33°	73°
Relative dark adaptation.	white	33°	88°
Relative bright adaptation.	red	20°	48°

} Lower part of the retina.

} Upper part.

In this experiment it was found that the extent of the part that causes pupillary movement is much smaller than that of the field of binocular vision.

That is, so far as the results of this experiment are concerned all the optic fibres seem to have no connection with the pupillary reaction. Moreover this point is made clearer by the following experiment on consensual reaction.

2. On the consensual reaction

It is *Cajal's* hypothesis that in those animals whose eyes, right and left, have not the common visual field, the optic nerves which issue from both of their eyeballs decussate completely and that in those animals whose right and left eyes, have the common visual field, the optic nerve fibres decussate completely.

Anatomical research teaches us that in those animals whose visual fields, right and left, are not common, for example, reptiles, amphibians, fishes, birds, and the lower mammals such as the guinea-pig, the optic fibres decussate completely in the chiasma; and in those animals whose right and left eyes, have the common visual field, for example, man, cats, dogs, goats, rats, rabbits, etc., the optic fibres decussate incompletely in the chiasma. The distribution of those optic fibres which do not decussate is as shown in Table 6.

Table 6.

Kinds of animals.	Tractus opticus.	Corpus genicul. lat.	Thalamus.	Colliculus superior.	Consensual reaction.
bird	decussate completely				—
guinea-pig	decussate completely				—
rabbit	→				—
rat	→	→			—
goat	→	→	→		—
dog	→	→	→	→	+
cat	→	→	→	→	+
man	→	→	→	→	+

Experimental: The author examined the consensual reaction of various animals with Hess's pupilloscope, and found that it occurred in man, cats, and dogs, but not in those animals whose optic fibres perfectly decussate in the chiasma,—for example, the guinea-pig; and in those animals which have a few optic fibres which do not decussate,—for example, rabbits, rats, and goats, there occurred no consensual reaction.

This fact accords with the result of Steinach's experiment and that of recent anatomical research, so that the superior colliculus is the indispensable organ to pupillary reflex movement and only those optic nerve fibres which pass this part, have conjunction with the pupillary reflex movement.

Then the author examined dogs, cats, and man as to whether the pupillary reaction of one eye necessarily accompanies the consensual reaction of the other or not, and found that in either case of direct or indirect vision, the pupillary reaction in one eye never occurs without being accompanied by the other as shown in Table 7 and Table 8.

Table 7.

Exrminees.	Quotient of Hess's pupilloscope.	Pupillary reaction of right eye.	Consensual reaction of left eye.
A	0.85	±	±
A	0.92	±	±
A	0.92	±	±
A	0.62	±	±
A	0.62	±	±
A	0.92	±	±
B*	0.18	±	±

* case of neuritis retrobulbaris.

Table 8.

Examinees.	Quotient of Hess's pupilloscope.	Pupillary reaction of right eye.	Consensual reaction of left eye.
A	0.62	+	+
A	0.29	+	+
A	0.12	±	±
A	0.40	±	±
A	0.12	—	—
B*	0.13	—	—

3. Entoptic light sensation and pupillary reaction.

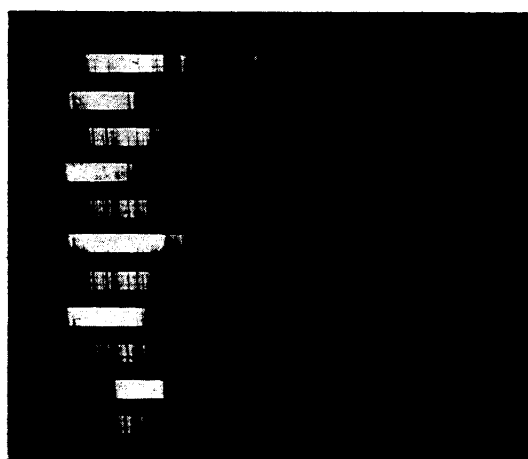
It was found that entoptic light sensation caused by the sudden pressure on an eyeball with the end of a finger, accompanies the pupillary movement in the other eye.

4. Ultra-violet rays and pupillary reaction.

Various methods to transmit the ultra-violet rays alone, cutting off the the visible rays into the eyes, have long been studied by many investigators, but a perfect method has not been found.

There are two methods generally used ; the one is *Lehmann's* modification of *Wood's* filter and the other is a colloidal solution of silver, prepared by the electrolytic method.

Prof. Dr. *Syozi* suggested to me the use of the ultra-violet glass made by *Chance Brothers Company*, which transmit the rays ranging from 306 μ . to 402.5 μ . as shown in Fig. 1. Consequently the author under-



Control. (no glass.)
 Fiezel, C.355 μ .
 Control.
 Amber, A.355 μ .
 Control.
 Japan-made meniscus....310 μ .
 Control.
 Filtray.350—505 μ .
 Control.
 ChanceBrother. ...306—402.5 μ .
 Control.

Fig. 1. Absorption spectra of different kind of glasses.

* case of neuritis retrobulbaris.

took the following experiment with this glass filter.

The apparatus used in the investigation are shown in Fig. 2.

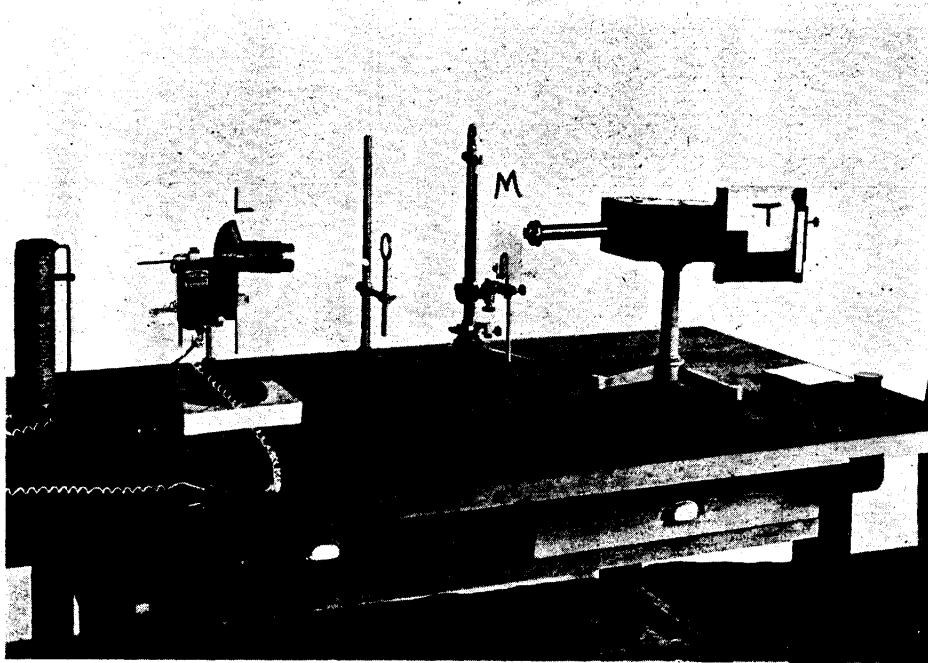


Fig. 2. An Illustration of my experiments on the ultra-violet rays and the pupillary reaction.

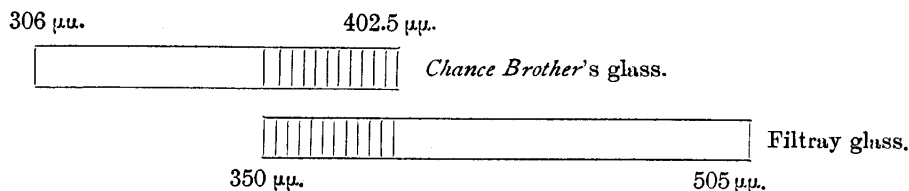
Various glass was placed as shown in Fig. 1 at a point M between a spectrograph and the light source L, and screened all visible rays of spectrum with a zinc plate T, letting ultra-violet rays alone pass into the eyeball of the examinee. As light source, an iron-arc was used.

All my examinees were under the age of twenty one years, since Professor Dr. Syozi's experiment shows that the lens absorbs the ultra-violet rays shorter than $321.5 \mu\mu$. of their wave length and the cornea, to $292.5 \mu\mu$. in case of a man, 23 years old, while the lens absorbs to $481.0 \mu\mu$. in case of a man of 65 years, and it is clear that the rate of the absorption of ultra-violet rays of lens depends much upon the age of the examinees.

Experimental: a. A Chance Brother's ultra-violet glass which admits only the rays of wave length 306 to $402.5 \mu\mu$. and a Filtray glass which admits only the rays of wave length 350 to $505 \mu\mu$. were placed one upon the other in front of the collimator M of a quartzspectroscope, as shown below and lighted the iron-arc to illuminate the pupil of an examinee, and the visible rays of spectrum produced by the quartz-

spectroscope were cut off with a zinc plate T. Then the Filtray glass alone was removed to increase the light intensity to the retina, and observed if any pupillary movement occurred or not.

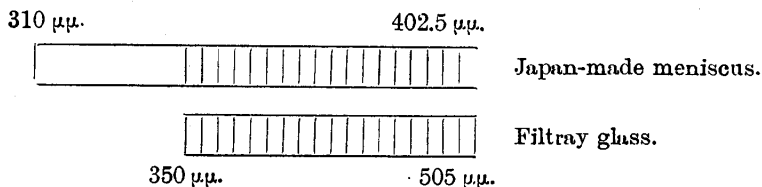
As the result no pupillary movement was observed at all.



Cutting off visible rays with a zinc plate, the rays from 350 $\mu\mu$. to the begin of the visible ray, filter these two glasses.

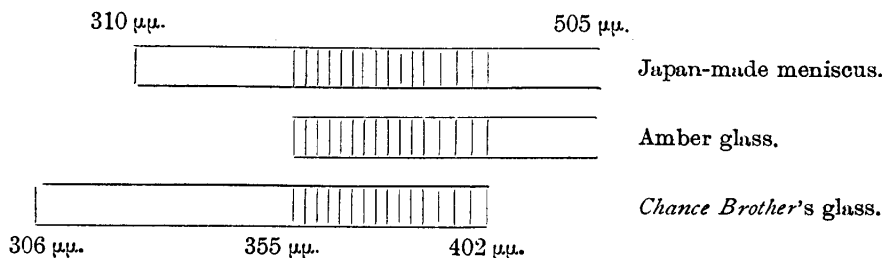
b. Putting a Japan-made meniscus and a Filtray glass in the same way as mentioned above and shown diagrammatically below, the pupillary movement was examined at the moment of the removal of the Filtray glass.

No alteration in the size of the pupil was observed by its illumination.



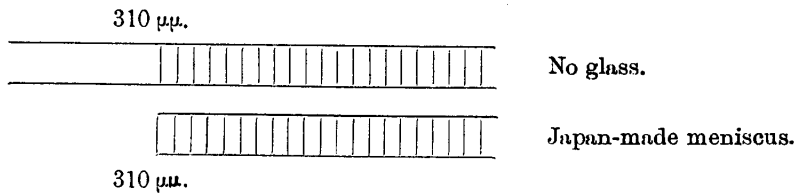
c. The author examined the pupillary reaction by illumination of the retina through a Japan-made meniscus, an Amber glass and a Chance Brother's ultra-violet glass in the usual way and no difference in the size of the pupil was observed.

The arrangement of glasses is shown below:

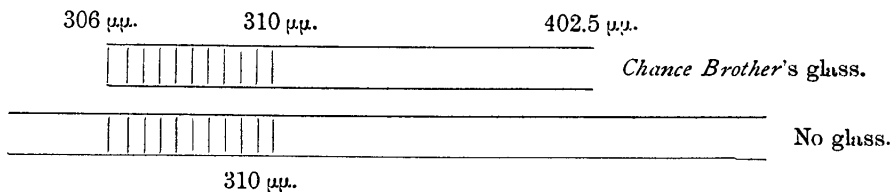


d. The author put a Japan-made meniscus alone in front of the collimator of the spectroscope cutting off all visible rays of spectrum by the method mentioned above and then removed the Japan-made meniscus, but there was no pupillary movement. On the contrary, if very feeble visible rays pass into the eye of an examinee, some contraction of the pupils was observed in all cases.

The arrangement is shown below:



e. The author put a *Chance Brother's* ultra-violet glass alone at a point M in the same way as in d, and further more cut off all the visible rays, and then shut off all the rays that passed through that glass. But there was no change in the size of the pupil.



f. The author had once an opportunity to examine the pupillary reaction on the subject whose left eye has no lens (some years ago it was extracted by the operation of cataract) while the right eye has normal one. With his left eye, this subject can see so clearly the ultra-violet rays (between 316 $\mu\mu$. to 385 $\mu\mu$. of wave length) which appear very dimly to his right eye that when he wishes to have nearly equal light sensation to the ultra-violet rays with either eye, the intensity of the rays entering into his left eye, must be reduced to the value of one hundredth of the original. When his left eye was illuminated by the ultra-violet rays with the wave length of 316 $\mu\mu$. to 385 $\mu\mu$. a distinct pupillary reaction on both of his eyes was observed.

That is, invisible rays never cause the contraction of the pupil, but in case the ultra-violet rays cause a light sensation to our eyes either by the fluorescence of the retina or by the direct excitation of the retina, they cause the pupillary movement. Judging from the results of the experiments noted above the author believes that *Gudden's* pupillary fibres are nothing but the fibres of the optic nerve themselves, and moreover the nerve fibres are those special optic fibres which run to the superior colliculus.

In 1908 *Hess* published that the so-called pupillary fibres are identical with optic fibres, and that the function of inducing pupillary movement in addition to the function of perceiving brightness has developed only in the neuroepithelium in the central part of the retina.

5. Accommodation of the eye and pupillary movement, convergence of the visual axes and pupillary movement.

When we change only the convergence of the visual axes by applying a prism, making an examinee gaze at a point A, as shown in Fig. 4. not to change accommodation, there always occurs a pupillary movement.

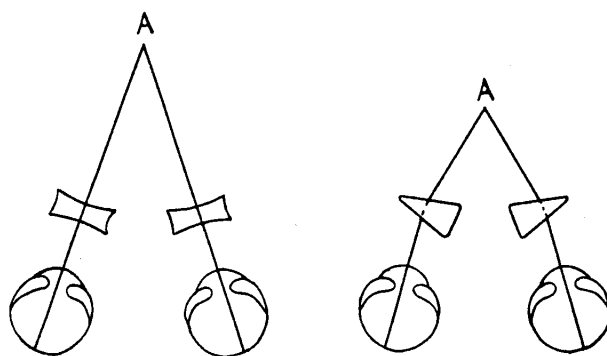


Fig. 3. and Fig. 4.

On the contrary, if we make an examinee gaze at a point A as shown in Fig. 3 and then change accommodation alone by applying convex lenses or concave lenses, there occurs no pupillary movement.

Therefore the pupillary movement does not attend to the accommodation itself, but convergence of the visual axes.

6. Critical discussion in respect to the diagrams of the pupillary reflex movement found in various books.

Though the investigation of the oculo-motor nucleus related with the pupillary reflex movement has been made for a long time, it is not yet made plain. But at present the most trustworthy theory is the one which was advanced by *Bernheimer*. According to his theory, *Edinger-Westphal's* nucleus is the central nucleus of the pupillary movement. Dr. *Tutida* thinks that the lateral nucleus of oculo-motor nerve containing small motor cells is the pupillary motor center. Thus we have not a decisive theory advanced about whether the fibres of the oculo-motor nerve sent out from the centres of the pupillary movement are decussate or not, but many scholars believe that they do not decussate and their centres are *Edinger-Westphal's* nuclei. Reasoning from the results of his experiment on the consensual reaction, *E. Steinach* made a conjecture in 1890 that the fibres of the oculo-motor nerve sent

nervous connection for the pupillary reflex movement which are met with in various books, on the ground of anatomical knowledge mentioned above and the results of his own experiments.

1. *Bach's* scheme shown in Fig. 5 and *Behr's* scheme in Fig. 6 are

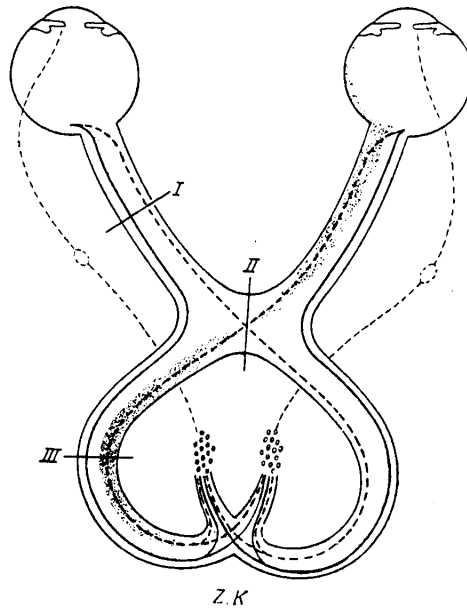


Fig. 6. Behr's scheme.

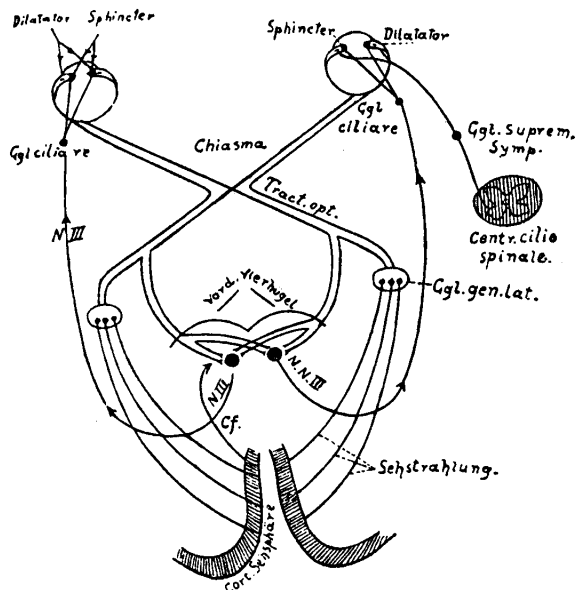


Fig. 7. Liepmann's scheme.

not correct, since these schemes show that pupillary reaction of one eye always gives rise to consensual reaction of the other eye even in those animals whose optic fibres decussate perfectly in the chiasma.

2. *Liepmann's* scheme shown in Fig. 7 is equally preposterous.

3. *Bing's* scheme shown in Fig. 8 is not correct from either anatomical or physiological points of view.

4. Considering *Cunningham's* scheme, it shows that if we illuminate the mesial half of the retina of one eye, there would not occur pupillary reaction of the eye, but there would occur consensual reaction of the other eye alone in any animal, no matter whether its optic fibres are decussate or not. This can not but be inconsistent. Because when the author illuminated the outer half or the mesial half of the retina in one eye, the indirect pupillary motor reaction in the other eye was almost the same in either case. This fact harmonizes with what *Weve* said.

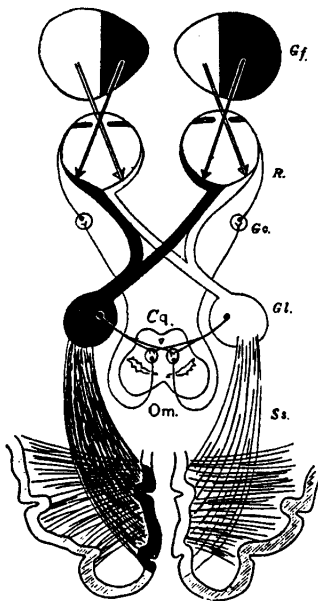


Fig. 8. Bing's scheme.

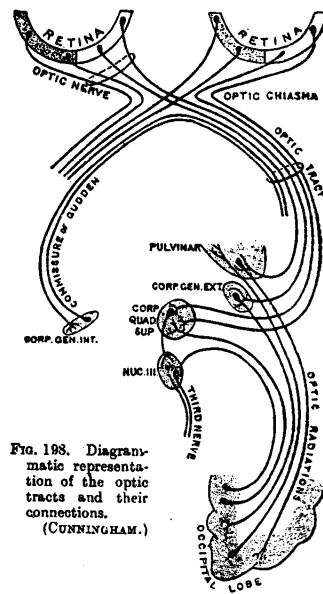


FIG. 198. Diagrammatic representation of the optic tracts and their connections. (CUNNINGHAM.)

Fig. 9. Cunningham's scheme

5. The present author believes *Levinsohn's* scheme shown in Fig. 10 is the best one of all the schemes mentioned above.

6. The present author's own schemes are shown in Fig. 11 and 12. They show that the optic fibres which induce pupillary reflex movement, issue from the same nerve cells in the retina with the optic fibres themselves and run to the superior colliculus of the quadrigeminal bodies. In those animals which have decussate optic fibres alone, there occurs pupillary reaction for light in one eye, but consensual reaction

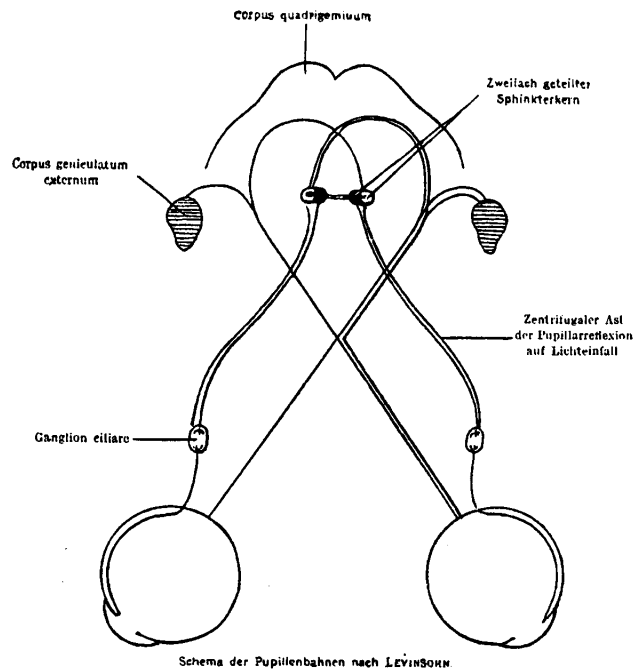


Fig. 10. Levinsohn's scheme.

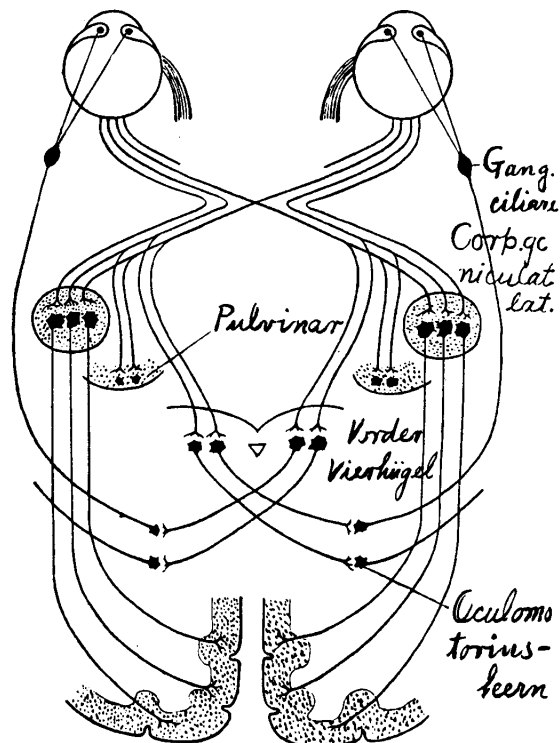


Fig. 11. Okuyama's scheme.

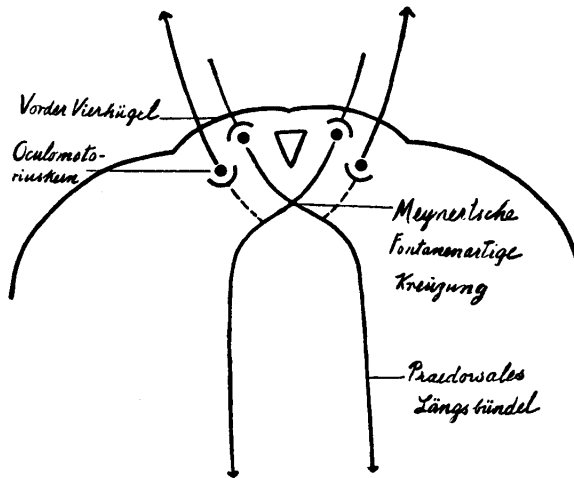


Fig. 12. Okuyama's scheme.

in the other never occurs; and in those animals which have not only decussate optic fibres but also non-decussate fibres passing through the superior colliculus of the quadrigeminal bodies, the pupillary reaction of one eye never occurs with accompanying the consensual reaction of the other, in either case of direct vision or indirect vision. In other words his scheme harmonizes with *Levinsohn's*

(In addition to those schemes of the nervous connection for the pupillary reflex movement, on which we have touched here, there are many other schemes,—for example, *Bechterew's*, *Axenfeld's*, *Schaefer's*, etc., but they are far from being correct.)

Summary.

1. The excitability of the different parts of the retina for the pupillary reflex movement was examined with *Hess's* differential pupilloscope.

2. The consensual reaction is observed in man, cats, and dogs, but found neither in those animals whose optic fibres decussate perfectly in the chiasma,—for example, guinea-pig, nor in those animals which have non-decussate fibres not running to the superior colliculus, — for example, rabbits, rats, and goats.

3. The so-called *Gudden's* pupillary fibres are identical with the optic fibres themselves, but their nerve fibres are nothing but the special optic fibres which run to the superior colliculus.

4. The pupillary movement does not attend to the accommodation of the eye itself, but convergence of the visual axes.

5. A new scheme of the nervous connection for the pupillary reflex

movement which explains all facts known without contradiction is advanced by the author.

In conclusion, I wish to express my hearty gratitude to Professor *Oinuma* for his kind direction, to Professor *Syozi* for his kindness in lending me an ultra-violet glass which was not easily obtainable as well giving me various suggestions for my research; and also to Professor *Kosaka* for his valuable instructions on the line of anatomy.

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