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ABSTRACT

The Hirschberg test is an objective means of determining the angle of strabismus by noting the distance the corneal reflex of a light source is from the center of the entrance pupil. A scale factor is used in converting the amount the reflex distance is in millimeters to prism diopters. Recent studies have demonstrated this factor to be 22 prism diopters for each millimeter. This study notes how axial length would effect this scale factor. Using ultrasound axial lengths of thirty eyes were measured and compared to the results of a Hirschberg simulation. A small effect results from this comparison. The mean values of scale factor determination noted twenty-three prism diopters per millimeter.

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Ocular Rotations and the Hirschberg Test

For some time the Hirschberg test has been used as an objective means of estimating the amount an eye deviates in strabismus, although it more specifically estimates the relative rotational postion of the eye. The test is performed by holding a light source in front of the patient and having him fixate the light. The smooth cornea will reflect an image of the light visible to the examiner. The position of the reflex relative to the entrance pupil, depends on where the eye is fixating. An eye which will fixate the light source normally, will have the reflex near the center of the entrance pupil of the eye or more commonly about 0.25 millimeters towards the nasal side. But as the eye fixates at a point other than the fixation target, as happens in strabismus, the corneal light reflex seen by the examiner will be in a position determined by the deviation of the eye from accurate fixation.

Julius Hirschberg[8], who originated the method, cited relationships between ocular deviation and apparent location of the corneal reflex. These are,

1) If the corneal light reflex is seen within the pupillary area, the deviation can range from 0-20 degrees of arc,

2) if the reflex is seen within the interval bounded by the pupillary margin and the limbus of the cornea, the deviation can range from 20-45 degrees,

3) if the reflex lies outside the limbus (on the sclera) then the deviation is greater than 45 degrees.

Krimsky[9] noted that the radius of curvature of the cornea is about eight millimeters. He reasoned that each millimeter on the corneal curvature would correspond to seven arc degrees. His reasoning is that each millimeter the reflex deviates from the center of the entrance pupil, or the apex of the cornea, corresponds to seven degrees of arc, or about twelve prism diopters deviation.

Other investigators have used similar scale factors for angular deviation per millimeter. Among them are Scobee[15] who claims tht eight degrees deviation is noted for each millimeter. Burian and von Noorden[3] agree with the seven degrees or twelve prism diopters quoted by Krimsky. More recently the Optometric Weekly[18] in a series of articles about strabismus for optometric assistants, claim that the amount of seven degrees or twelve prism diopters for each millimeter from the center of the entrance pupil is the scale factor to use.

Krimsky[9] noted that the rotation of the eye was the crucial factor, not the curvature of the cornea. Although the rotation isn't directly measured in the Hirschberg test, the amount of deviation of the strabismic eye should equal the amount of rotation of a normal eye to that deviating position. He points out that the curvature of the cornea doesn't affect the rotation or the strabismus and that the apex of the cornea would move with the rest of the eye. This idea was further advanced by Jones and Eskridge who noted that their results using Krimsky's conversion ratio grossly miscalculated actual deviations they measured.[8] They theorized that the distance from the center of curvature of the cornea and the center of the entrance pupil was constant at all rotations of the eye. And that the center of curvature of the cornea moved as well as the reflex in the various rotations of the eye.

They derived a mathematical formula which determined the position of the corneal reflex with any rotation of the eye. The distance between the reflex and the center of the entrance pupil they labelled <u>h</u>. The distance between the corneal center

T A B L E   O N E

Center of Rotation Determined by Early Investigators
recorded in millimeters behind the cornea

	Emmotropic Eye	Myopic Eye	Hyperopic Eye
Axial Length	23.53	25.55	22.10
Donders	13,54	14.52	13.01
Mauthner	13.73	13.22	15.64

of curvature and the entrance pupil center, they labelled r. This distance (h) equalled the distance r times the sine of two angles, the angle of rotation of the eye (θ) and angle Kappa ($\emptyset$). or h= r sin ($\theta+\emptyset$). Using Stenstrom's[16] data for the eye, an average r of 2.93 millimeters was introduced giving an average h of one millimeter equalling 12.2 degrees or 21.6 prism diopters.

They tested the above ratio (21.6 prism diopters/millimeter) in subjects who were asked to fixate a target at various distances on either side of the straightforward position. By photography, they were able to determine how much the corneal light reflex deviated from the center of the entrance pupil of the eye (h) and the relation of this deviation to known amounts the eye had rotated (θ). Their averaged results closely resembled the scale factor their mathematics predicted.

Griffin and Boyer[5] tested these results using a number of known strabismic cases. They also photographed the position of the corneal light reflex from the center of the entrance pupil and compared these amounts to the measured strabismus angle of the subject. The amount was determined from the cover test. Their results exhibited a mean close to 22 prism diopters for each millimeter the reflex was from the center of the entrance pupil.

The results, however, showed a large standard deviation. Griffin[6] points to the work he has done and that of Jones and Eskridge and the controversy that seems to prevail on the proper scale factor (prism diopters per millimeter) to use for the Hirschberg test. He explains the importance of keeping up with modern developments. One such development has been the realization that the angle Kappa and its influence on the estimated is not zero in most people, as early investigators assumed in their work with the Hirschberg test. He explains that it is important to include angle Kappa in any evaluation of the Hirschberg test.[7]

Hereafter, the distance from the center of the entrance pupil to the reflex will be referred to as the amount the reflex has "moved." Thereflex itself doesn't move but the position it taked would be exhibited when the eye moves. This includes the assumption that angle Kappa is zero or that its effects have been accounted for, making it zero.

The value of r used in the data by Jones and Eskridge was an average value of r; there are a variety of r values as there are a variety of eyes. It would seem then that the ratio devised by Jones and Eskridge would be influenced by a few uncontrolled variables, the most obvious being the value of r. Another variable, the axial length of the eye might have an effect on ocular rotations. The assumption is that the geometric center of the eye will serve as the center of rotation, a similar assumption that Perkins, et. al.. used.[14] A larger eye would rotate a certain distance of arc to have its corneal apex reach a particular point. A shorter eye would rotate a shorter distance of arc to reach that same point. Despite the fact that the rotational amount in degrees of arc is the same the distance travelled is different. Perkins noted this difference with steel balls of various curvatures and centers of rotation.[14]

Determining the center of rotation hasn't been too easy. Stevens[17] quotes two early investigators who determined the center of rotation. These values are noted in Table one. Later investigators claimed that these methods were crude. Donders method, which involved geometry, was under the criticism that the very point he was trying to determine was assumed in his calculations. His stated center of rotation for the emmetropic eye has been widely accepted, however, as the best approximation for the center of rotation of the emmetropic eye.[2,8,11,12] Some investigators have shown similar amounts.[13]

Park and Park[13] noted that there isn't one point acting as the center of rotation, but a number of points which vary as the horizontal gaze decreases or increases. They gave an average value, however, of 13.8 millimeters behind the cornea, somewhat similar to Donder's value.

Perkins, Hammond, and Milliken[14] used the assumption that the center of rotation will serve as the radius of the globe and that twice this radius would give the axial length. Their determination of the radius was derived from the formula CX (radius) $= XY / 2 \times \sin \theta / 2$, where XY is the change in the corneal light reflex position as the eye rotates through angle θ. Their results for the axial length indicate a consistent three millimeters greater than that obtained by x-ray and ultrasound techniques. The XY value resembles the reflex "movement" distance and Eskridge and Jones' <u>h</u> value. Then if the distance (<u>h</u>) were substitued for the XY value in the equation, and assign θ a constant, it is observed that the value of <u>h</u> relies on the radius of the globe.

Despite the problems involved with measuring the center of rotation, axial length would influence the position of the rotation center. Donder's data indicates this possibility.[17]

It would be of benefit, then, to investigate any effects the axial lengths of a number of subjects has on their responses to the Hirschberg test.

METHOD

Axial lengths were determined with the use of ultrasonagraphic techniques. In the time-amplitude system described by Goldberg and Stein[8], a transducer capable of sending and receiving the ultrasound waves was placed on the cornea. Sound waves travelled throughthe eye being reflected by the various structures of the eye. These "echoes" were picked up by the transducer and then displayed on an oscilloscope screen separated by the variable time elements that the reflections occur. A Polaroid photograph gave reproductions of the oscilloscope screen. Measurements were made of the separation of the echoes and converted to distances incorporating a conversion factor derived from a glass standard and the speed of sound through the various media involved.

To note the eye's rotational effects on the corneal reflex a light source was placed in front of the subject. The source was a household 100 watt bulb, attached to a variable resistor to adjust the amount of light that is used. Aluminum foil was wrapped around the bulb to enable a small light to serve as the reflex. A semi-reflecting glass was placed in front of the eye to allow the light to pass as well as a photograph of the eye to be taken. To each side of the subject a target with five fixation marks was placed. For conveience of calculations and construction of the target, it was placed a total of one meter from the eye. The semi-reflecting glass enabled the subject to see the target. The subject was then asked to first fixate the first mark and a photograph was taken. The subject was then asked to fixate the second target separated from the first by two degrees and a second photograph was taken. The process continued until all five fixation marks were viewed by the subject. Both eyes of fifteen subjects were used in the set-up, Each of the fifteen subjects were determined not to have any eccentric fixation, using monocular light fixation technique. A Nikon camera was used with tri-X Pan film (ASA 400). The camera was focused with the lenses once and any further focusing was done by moving the camera or the subject forward and backward to insure a constant magnification factor. A millimeter rule was also photographed to derive a conversion factor for the photograph measures.

RESULTS

Table Two is a record of the axial lengths noted for each subject. The ultrasound pictures gave four distinct echoes for each of the four parts of the eye, the cornea, the anterior lens surface, the posterior lens surface, and the back of the eye or the sclera. The distance between these echoes represent the various media the sound waves travelled through, the vitreous, the lens substance, and the aqueous. The conversion factor determined from the glass standard involved two surfaces separated by the glass media. The distance between the surfaces was known as well as the speed of sound conversion facter through the glass material. In measuring the distance shown on the photograph, this known conversion was applied to determine the actual distance. The conversion factors thus determined was equal to 0.583 microseconds/millimeter. For each of the media, a further conversion involved the usage of the speed of sound through these various media; for the vitreous and the acqueous, the conversion factor is 1.532. And for the lens substance the conversion factor is 1.640. The measurement of the photograph was converted to a measurement by multiplying it by the conversion factor for each of the media.

T A B L E   T W O

Axial lengths determined by ultrasound, in millimeters

SUBJECT	EYE	A	B	A+B	C	Axial Length
J.R.	O.D.	3.13	3.83	6.41	19.31	25.72
	O.S.	3.49	3.61	7.09	18.39	25.48
J.H.	O.D.	2.77	4.44	7.22	15.32	22.54
	O.S.	3.06	4.36	7.43	15.73	23.16
C.N.	O.D.	3.13	3.49	6.62	16.97	23.59
	O.S.	3.25	3.43	6.68	16.56	23.23
D.C.	O.D.	2.50	3.93	6.43	14.63	21.06
	O.S.	2.93	3.99	6.91	14.49	21.40
D.B.	O.D.	3.33	3.59	6.93	18.25	25.06
	O.S.	3.18	3.59	6.79	18.06	24.84
C.L.	O.D.	2.37	3.65	6.02	15.61	21.63
	O.S.	2.69	3.04	6.73	19.52	21.96
K.D.	O.D.	3.25	3.16	6.41	19.31	25.72
	O.S.	3.69	3.04	6.73	19.52	26.25
D.F.	O.D.	3.37	3.32	6.69	17.48	24.17
	O.S.	3.29	3.38	6.67	17.54	24.20
L.R.	O.D.	2.65	3.53	6.18	15.90	22.08
	O.S.	3.32	3.38	6.69	16.18	22.87
W.C.	O.D.	3.04	3.54	6.58	15.67	22.24
	O.S.	3.13	3.64	6.77	15.82	22.59
R.H.	O.D.	3.04	3.66	6.70	14.30	20.99
	O.S.	2.90	3.37	6.27	14.35	20.62
J.L.	O.D.	3.70	3.38	7.08	17.15	24.23
	O.S.	3.04	3.41	6.45	17.21	23.66
B.C.	O.D.	3.64	3.42	6.97	16.33	23.39
	O.S.	4.50	3.05	7.55	16.36	23.91
P.D.	O.D.	2.43	3.90	6.33	14.42	20.75
	O.S.	2.40	4.26	6.60	14.22	20.82
J.C.	O.D.	3.16	3.44	6.60	14.34	20.93
	O.S.	3.48	3.54	7.02	15.33	22.35

As the representation is of time, however, to the structure and back, the result needs to be divided by two. This result gives a measurement of the distances through the media. The distance through the acqueous from the front of the cornea is labelled <u>A</u> on the table, through the lens is labelled <u>B</u>, and through the vitreous is labelled <u>C</u>.

Measurements of the corneal reflex were accomplished by measuring them from the temporal limbus. This limbus was easy to see and insured an easier reading as the pupil size varied and finding its center was difficult. These measurements were converted into actual measurements by using the photograph of the millimeter rule and sometimes cross checking by an actual measurement of the cornea. The results of the measurements are shown in Table Three.

The distances were subtracted for each two degree segment and averaged for a mean distance which was recorded on the table. A standard error for the two degree mean was also computed and results appear on the table. Also included on the table is a projection of the amount the reflex would "move" for twelve degrees. This projection is from simple mathematical calculations.

T A B L E   T H R E E

data collected from photographs, recorded in millimeters

Subject	Eye	Axial Length	Distance to position 0	1	2	3	4	Ave.	Standard Error	12°
J.R.	O.D.	25.28	7.15	7.27	7.38	7.60	7.89	0.19	0.038	1.11
	O.S.	25.48	7.63	7.79	8.00	8.17	8.33	0.18	0.012	1.05
J.H.	O.D.	23.66	8.11	8.25	8.46	8.67	8.88	0.19	0.021	1.13
	O.S.	22.54	7.17	7.38	7.55	7.75	—	0.19	0.007	1.13
C.N.	O.D.	23.59	7.58	7.71	7.92	8.08	8.25	0.17	0.028	1.01
	O.S.	23.23	8.00	8.21	8.41	8.56	8.75	0.19	0.010	1.13
D.C.	O.D.	21.18	6.38	6.58	6.71	6.79	6.92	0.14	0.022	0.84
	O.S.	21.40	7.18	7.29	7.38	7.53	7.75	0.14	0.033	0.84
D.B.	O.D.	25.06	6.46	6.54	6.63	6.67	6.75	0.07	0.013	0.44
	O.S.	24.84	7.25	7.33	7.46	7.54	7.63	0.10	0.021	0.57
C.L.	O.D.	21.63	6.17	6.29	6.42	6.54	6.63	0.12	0.014	0.69
	O.S.	21.96	5.75	5.83	5.92	6.04	6.21	0.12	0.021	0.69
K.D.	O.D.	25.72	5.67	5.75	5.84	5.96	6.07	0.10	0.012	0.60
	O.S.	26.25	6.79	6.92	7.04	7.17	7.25	0.11	0.014	0.69
D.F.	O.D.	24.11	5.83	6.00	6.08	6.21	6.38	0.14	0.023	0.83
	O.S.	24.30	6.88	7.00	7.17	7.31	7.38	0.13	0.022	0.75
L.R.	O.D.	22.08	6.21	6.33	6.46	6.58	6.79	0.15	0.021	0.87
	O.S.	22.87	7.68	7.73	7.95	8.09	8.27	0.15	0.037	0.89
W,C,	O.D.	22.25	7.29	7.46	7.58	7.71	7.92	0.16	0.021	0.95
	O.S.	22.59	7.79	7.96	8.08	8.17	8.42	0.16	0.026	0.95
R.H.	O.D.	20.99	8.19	8.26	8.33	8.42	8.54	0.09	0.010	0.52
	O.S.	20.[illegible]	7.49	7.58	7.71	7.79	7.92	0.11	0.011	0.65
J.L.	O.D.	23.66	8.13	8.29	8.46	8.63	8.75	0.16	0.012	0.93
	O.S.	24.24	7.29	7.50	7.58	7.79	7.92	0.16	0.031	0.95
B.C.	O.D.	23.39	7.29	7.50	7.67	7.79	8.00	0.18	0.021	1.07
	O.S.	23.91	7.79	7.95	8.08	8.25	8.71	0.23	0.077	1.38
P.D.	O.D.	20.75	7.75	7.92	8.17	8.33	8.56	0.20	0.022	1.22
	O.S.	20.82	6.95	7.13	7.25	7.42	7.63	0.17	0.018	1.02
J.C.	O.D.	20.93	8.09	8.16	8.25	8.33	8.50	0.10	0.022	0.61
	O.S.	22.35	6.79	6.92	7.04	7.16	—	0.13	0.003	0.74

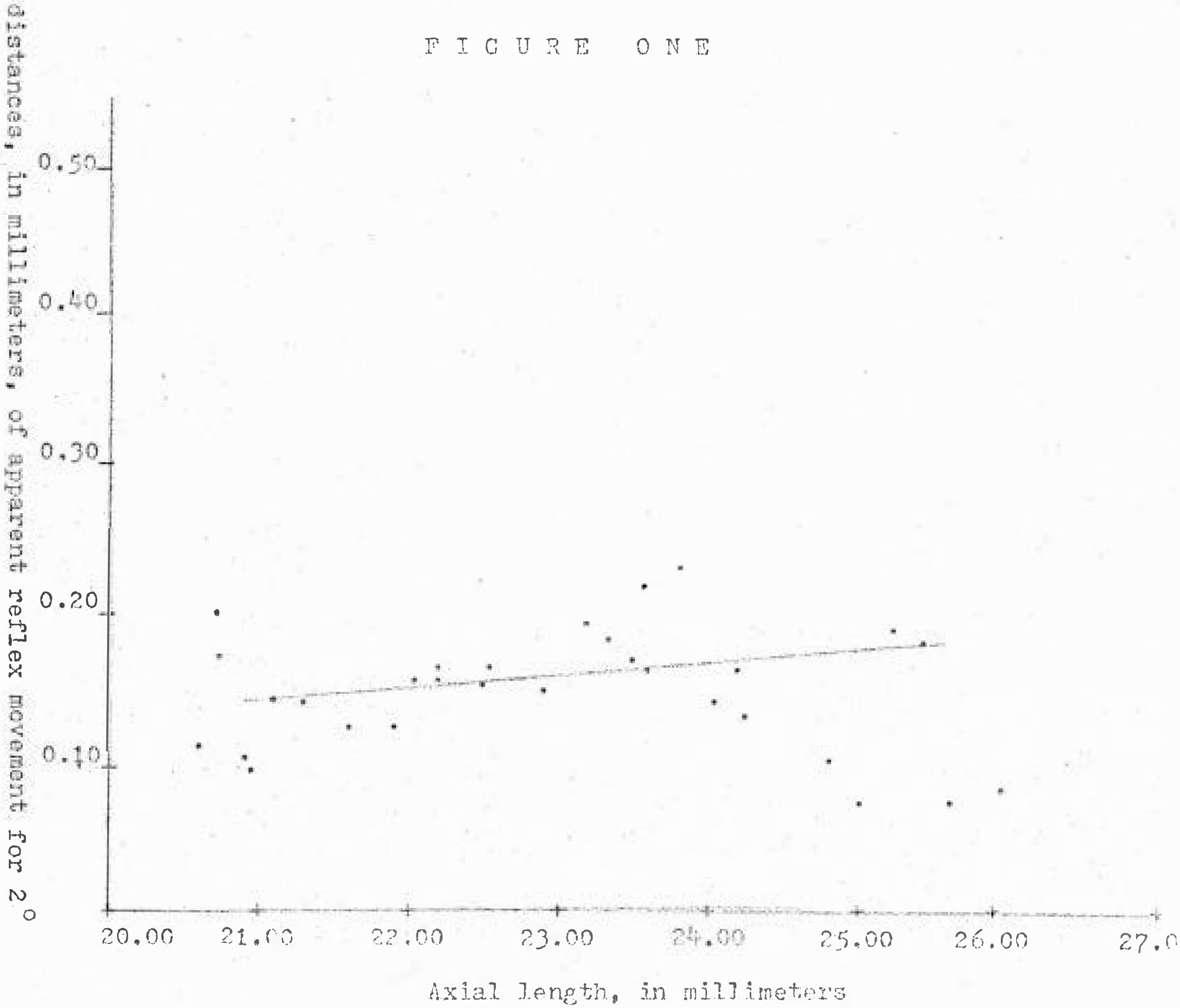
The mean for the two degree rotation is 0.15 millimeters, with a standard deviation of 0.04 millimeters, and for the projected twelve degrees rotation, the mean is 0.87 millimeters with a standard deviation of 0.24 millimeters. These results convert to a mean of 23.33 prism diopters for each millimeter of "movement" with a standard deviation of four prism diopters.

Figure One is a scattergraph of the two degree rotation reflex distances as compared with the axial length. The line that is drawn in the figure is an observed best fit line, disregarding the few radically differing points. The line shows a slope of 1/10, or for each 1.0 millimeter change is axial length, there is 0.01 millimeter change in reflex "movement." The change is in like directions, suggesting that an increase in axial length will show a small increase in reflex "movement." A statistical analysis of the data using Pearson's correlation coefficient shows a correlation of 0.27.

CONCLUSION

The difference in the center of rotations of the various sized eyes was the basis for the question posed of any effects of the axial length on the Hirschberg test. The

FIGURE ONE


distances, in millimeters, of apparent reflex movement for 2°
0.50
0.40
0.30
0.20
0.10
20.00
21.00
22.00
23.00
24.00
25.00
26.00
27.00
Axial length, in millimeters

assumption was made that the center of rotation was in the geometric center of the eye. But it was pointed out that the center of rotation is not in the center of the globe, but varied. Donders early data indicates a difference of 1.51 millimeters between the small eyes' and large eyes' center of rotation, a difference in the reflex movement of 0.05 millimeters.

Errors noted in the data may have come mostly from observational errors. All measurements were fine measurements using the travelling microscope. Inaccuracies of ± 0.015 millimeters were possible in the readings. Using the conversions introduced for an actual measure from the photograph, a possible differece of ± 0.06 millimeters is present. This is a resemblance of the differences noted in the reflex "movements" calculated from Donders data.

This study, and two others before it[5,8], indicate that the popularized conversion factor of one millimeter of movement for twelve prism diopters of deviation is a low estimate. The results in this study indicate there is a mean of 13.33 degrees or twenty-three prism diopters for each millimeter of "movement."

Another aspect of this study emerges from the fact that the highly myopic eyes of subjects D.B. and K.D. show unexpectedly small amounts of movement. Also, the hyperopic eyes of subject P.D. show an unexpectedly great amount of movement. The scattergram shows a wide variety of similar unexpected results, indicating that other factors may be involved in the Hirschberg test. Some of these factors may rely on the muscle strength of the ocular muscles, the whole size of the eye (our concern was for the axial length), the weight of the eye, any eccentric fixations, of the variable physical size of the subjects involved. The fact that the center of rotation varies with the horizontal gaze may also influence the results towards the unexpected.

In this experiment, deviations from linearity of the relation between corneal reflex displacement and angular rotation, as well as intersubject variations in scale factor (prism diopters per millimeter) are so much smaller than those to be expected when performing the customary Hirschberg test evaluation, that, for clinical purposes, they are insignificant.

SUMMARY

With the varying scale factors recommended for objectively estimating strabismus angle using the Hirschberg test, further

study was needed to verify findings of recent investigators[5,8]. This study included an investigation of the subjects axial lengths and their possible effects on the Hirschberg test. Although an effect was shown, its results are insignificant as it represents a small amount. Results showed a scale factor of twenty-three prism diopters per millimeter displacement of the corneal reflex from the entrance pupil center. This value is very close to those found and recommended by Eskridge and Jones[8], and also by Griffin and Boyer[5].

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