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Abstract
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A STUDY OF THE EFFECTS OF PUPIL SIZE ON THE NEARPOINT CROSS-CYLINDER TESTS

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PROBLEM

To test the effect of pupil diameter on the near point refractive error as measured by the 14A, 14B complex.

Illumination at the pupillary plane will be altered so as to vary the pupil size without affecting directly the target illumination. Three constant illumination values will be used to yield three different pupil sizes.

Near point measurements will consist of a 14A plus pre-set, 14B plus pre-set, and a 14B pre-set from "P".

APPARATUS

A standard 45°-135° cross grid card was used as a target for all near point measurements. The target was cut 3½ inches in diameter and mounted ¾ inch in front of a 6x6 inch piece of transluscent glass. The glass, serving as a diffuse illuminating surface, was back illuminated by a 300 watt bulb that was encased so as not to allow extraneous light to disperse throughout the room. A ½ inch collar of black paper prevented light from overflowing onto the target, thereby allowing constant target illumination.

Into the ¾ inch space between the glass and the target there could be placed two 6x6 inch sheets of polaroid that served as a neutral density filter. They were so oriented as to allow only 2.4 foot-candles to reach the pupillary plane.

The room was indirectly illuminated by a 15 watt buld that was directed toward a 24 inch square sheet of black paper placed on the wall behind the phoropter. The bulb was shielded on the room side so that the small amount of light emitted would be reflected from the black paper.

All measurements were made in an examination room. The entire lighting apparatus was placed so that the target was 16 inches in front of the phoropter. A black phoropter was used so that reflection could be kept to a minimum.

Three illuminations were used. A minimum illumination in which the room was essentially dark except for the small amount of light given off by the 15 watt bulb. The illumination at the pupillary plane was .04 foot-candles as measured by the Luckiesh-Taylor Brightness Meter. At medium illumination, the 300 watt bulb was turned on and the neutral density filter was placed in front of the diffusing glass. This allowed only 2.4 foot-candles to reach the pupillary plane. At maximum illumination, the filter was removed from in front of the glass. This allowed 86 foot-candles to reach the pupillary plane.

In order to determine the proper number of foot-candles in each of the three illuminations that would yield the desired pupil size, we refered to the IES Handbook, Table 2-6. These values of average pupil size versus illumination were varied slightly in order to produce the desired effect for our experimentation purposes.

These three illuminations were determined by measuring a 4 inch square piece of constant feflectance paper with the Luckiesh-Taylor Brightness Meter. The meter was placed just behind the cross grid target and shielded from the source. The meter was directed toward the reflectance paper which was placed at the pupillary plane. The paper had a constant reflectance of 50% ± 1% between the wavelenghts of 460 millimicrons and 700 millimicrons as determined by the General Electric Spectrophotometer.

At both medium and maximum illuminations, the reostat attached to the 300 watt bulb was at maximum so that color temperature would be constant.

PROCEDURE

1. The subject was placed in a refracting room where pre-testing was performed to determine his best subjective refraction. The tests used to determine best subjective refraction included all of those in the #7 complex of the standard Optometric Extension Program (OEP) routine. Also, Dr. C. B. Pratt's near cylinder test was used to refine the cylinder axis and power. This value was then used as a pre-set condition for each of the tests in the experiment.
2. The subject was then taken to another examination room which contained the testing apparatus and placed in the examining chair facing the apparatus.
3. The illumination was lowered to the minimum setting (.04 foot-candles) and the subject was allowed to adapt to this level for 4 minutes. The size of the pupil of the subject's dominant eye was then measured as he fixated the test target. This measurement was made by one of the examiners who was previously adapted to a very low level of illumination.
4. The subject was then tested by a second examiner with the OEP monocular cross cylinder test (14A) using a +2.00 diopter pre-set. Plus was reduced until the subject reported first equal or first reversal. This was immediately followed by the binocular cross cylinder test (14B) as in the standard OEP routine, still using the plus pre-set. Measurements were

recorded when the subject reported last equal or first reversal. Sphere power was then reduced to the best subjective refraction level and a 14B was taken using a minus pre-set. Again, measurements were recorded when the subject reported last equal or first reversal.

5. Room illumination was then changed to the medium level (2.4 foot-candles). Again, the subject was allowed to adapt to this level for 4 minutes, and his pupil size was measured. The #14 tests were repeated at this level of illumination exactly as above.

6. Illumination was increased to maximum (86 foot-candles), and the same procedure as given above was repeated.

RESULTS

All graphs, tables, and statistics compiled were rounded off to the nearest .06 diopter. This value was chosen because physical measurements cannot be made less than this, yet accurate mathematical calculations and comparisons are attainable. Thirty-nine subjects were selected for our study whose ages ranged from 20-38 years with a mean age of 24.4 years. These subjects were separated into two categories: (1) twenty-five subjects with maximum, minimum, and medium pupil sizes of 7.5 ± .5mm, 5.0 ± .5mm, and 2.0 ± .5mm respectively comprised the first group. As this is a tightly controlled group, it is to be used as the basis for all statistics, comparisons, and conclusions; (2) fourteen subjects with pupil sizes larger or smaller than above were analyzed separately to determine if pupil size was a dominant factor in this experiment.

Statistics were compiled with the T-test (Table II) and considered significant when the null hypothesis was rejected and the results fell within the 95th percentile. Selection of the T-test was based on our related samples and interval data. Further clarification of our results was determined by finding the mean and the standard deviation of the data. Standard deviation (or variance) is a type of measure which helps to clarify the shape of the distribution and indicates how the observations are spread out from the mean.

The results for Group I were compiled in Table I. Here the net findings for +14A, +14B, and -14B were averaged for each subject and the differences from the average for each illumination was tabulated.

Results from the +14A, as presented on Table I and Graph I, are as follows. Comparison of the minimum to medium pupil sizes reveals a mean difference of .25 diopter more plus at the medium pupil size, which is statistically significant to the 99th percentile. Variation in the standard deviation of .17 from minimum to medium indicates a wider variance of the observations with a minimum pupil size. A difference in the +14A of .12 diopter more plus from medium to maximum pupil size rejected the null hypothesis and is, therefore, statistically significant to the 95th percentile. Differences of the standard deviations show a variance of .10 from medium to maximum measurements with the maximum pupil findings showing the greatest variance from normal. Comparison of minimum to maximum findings indicated a .37 diopter difference. This magnitude was also significant to the 99th percentile. The difference in standard deviation between the maximum and minimum pupil groups was negligible.

The +14B findings are presented in Table I and Graph II. Comparison of the minimum pupil findings to medium pupil findings show approximately .12 diopter more plus at the medium level, significant to the 95th percentile. The variance shown by the difference of the standard deviation of these two levels was very small (.03). The mean difference between the medium and maximum pupil findings was .06 diopter more plus at the maximum pupil size. This was not statistically significant at the 95th percentile level, but the increase plus trend is still shown. Variance between these two groups again was negligible. Comparison of the means for minimum and maximum pupils show a mean difference significant to the 99th percentile; the maximum pupil measurements having almost .25 diopter more plus than the minimum pupil size observations. Variance between these two groups was, again, low.

The Group I -14B findings, when analyzed, showed no statistically significant difference for the different pupil sizes. There was, however, the same general trend as shown in the other tests. When going from minimum pupil size to maximum pupil size, there was an increase of plus shown at each testing level. The variance, as analyzed in the previous tests, again, is least variable for the medium pupil size measurements.

Extreme pupil sizes, Group II, indicate a prevalent number of inconsistancies when compared to the controlled group as well as inconsistancies within the group. With only fourteen subjects classified into this group, a statistical analysis would not be mathematically valid. Even so, means and standard deviations were calculated for Group II. Results show, with the exception of one comparison set (minimum to medium pupil finding), that the same general trend was indicated for all +14A observations (Table I and Graph IV). In the aforementioned comparison we found a decrease in plus from minimum to medium pupil findings of about .06 diopter. From medium to maximum and minimum to maximum pupil testing in +14A, an increase in plus of .19 diopter and .12 diopter was found respectively. All variances were nearly identical, but approximately .15 smaller than Group I.

Table I and Graph V indicate +14B comparisons were also inconsistant; this time exactly the converse trend noted in the preceding paragraph. That is, a slight increase in plus from minimum to medium findings, and decrease in plus with both medium to maximum and minimum to maximum comparison of measurements. As above, standard deviations were nearly identical.

Finally, the -14B (Table I and Graph VI) indicates a decrease in plus of .12 diopter from the maximum to medium comparison. No change was found from observations taken between the minimum to maximum set of findings. The variances were, again, very nearly the same.

TABLE I

PATIENT NUMBER	+14A FINDINGS AVERAGE AND INDIVIDUAL DIFFERENCE FOR EACH ILLUMINATION				+14B FINDINGS AVERAGE AND INDIVIDUAL DIFFERENCE FOR EACH ILLUMINATION				-14B FINDINGS AVERAGE AND INDIVIDUAL DIFFERENCE FOR EACH ILLUMINATION			
	AVGE	MIN	MED	MAX	AVGE	MIN	MED	MAX	AVGE	MIN	MED	MAX
1.	1.43	+.06	-.43	+.31	0.81	-.06	-.06	+.18	1.50	-.50	+.25	+.25
2.	1.81	-.81	-.06	+.43	1.31	-.06	-.06	+.18	1.43	-.18	-.18	+.37
3.	2.31	-.06	+.18	-.06	1.56	+.43	-.56	+.18	2.00	+.25	-.25	0.00
4.	1.50	-.25	0.00	+.25	1.06	-.31	+.18	+.18	1.18	-.18	+.06	+.06
5.	1.50	-.25	+.25	0.00	0.81	-.06	+.18	-.06	0.93	+.06	+.06	-.18
6.	1.56	-.31	+.18	+.18	1.31	+.18	-.31	+.18	1.25	0.00	-.25	+.25
7.	2.31	-.31	+.18	+.18	1.68	-.43	+.06	+.31	1.93	-.43	+.06	+.31
8.	2.75	-.25	0.00	+.25	2.06	-.06	+.18	-.06	2.06	+.18	-.06	-.06
9.	1.75	0.00	+.25	-.25	1.31	-.06	+.18	-.06	1.50	0.00	0.00	0.00
10.	1.18	-.43	-.18	+.56	0.50	-.50	0.00	+.50	0.68	-.43	-.18	+.56
11.	1.67	-.18	-.18	+.31	1.43	+.31	-.43	+.06	1.56	+.18	-.06	-.06
12.	0.75	-.25	0.00	+.25	0.25	0.00	0.00	0.00	0.50	-.25	0.00	+.25
13.	2.25	-.50	+.50	0.00	1.56	-.31	+.43	-.06	1.81	-.06	+.18	-.06
14.	2.00	-.50	+.25	+.25	1.06	-.56	+.43	+.18	1.18	-.43	+.31	+.12
15.	1.31	-.56	+.18	+.43	0.68	-.43	+.06	+.31	0.56	-.06	+.18	-.06
16.	1.56	-.06	+.18	-.06	1.18	-.18	+.31	-.18	1.43	+.12	+.12	-.18
17.	1.68	-.18	+.06	+.06	1.00	-.50	+.50	0.00	0.81	-.56	+.43	+.18
18.	3.06	-.06	+.18	-.06	2.75	0.00	+.25	-.25	2.75	0.00	+.25	-.25
19.	0.50	-.25	0.00	0.00	-.25	0.00	0.00	-.25	-.31	+.31	-.18	-.18
20.	1.31	+.18	-.06	-.06	0.43	-.43	+.06	+.31	0.56	+.18	-.06	-.06
21.	1.68	-.68	+.12	+.62	1.25	-.50	0.00	+.50	1.31	-.31	-.06	+.43
22.	1.06	+.43	-.56	+.18	0.56	+.18	-.31	+.18	0.75	+.25	-.25	0.00
23.	2.00	0.00	0.00	0.00	1.43	+.06	-.18	+.12	1.50	0.00	0.00	0.00
24.	1.56	-.06	-.06	+.18	0.87	+.06	-.18	+.06	1.06	+.43	-.06	-.81
25.	1.75	-.25	0.00	+.25	1.25	0.00	0.00	0.00	1.68	+.06	-.18	+.12
Average	1.69				1.12				1.25			

The following is an example of the T-test used to determine the significance of the data. The example below is a comparison between 14A plus pre-set minimum pupil size and 14A plus pre-set medium pupil size.

H_o: No significant difference exists between the +14A minimum pupil results and the +14A medium pupil results.

H_A: A significant difference does exist between the +14A minimum pupil results and the +14A medium pupil results.

Sample No.	X_1	X_2	d	$d-\bar{d}$	$(d-\bar{d})^2$
1.	00	+.25	+.25	00	0000
2.	-.43	-.18	+.37	+.12	.0144
3.	-.18	-.18	00	-.25	.0625
4.	-.25	00	+.25	00	0000
5.	-.50	+.50	+1.00	+.75	.5600
6.	-.50	+.25	+.75	+.50	.2500
7.	-.56	+.18	+.75	+.50	.2500
8.	-.06	+.18	+.25	00	0000
9.	-.18	+.06	+.25	00	0000
10.	-.06	+.18	+.25	00	0000
11.	-.25	00	+.25	00	0000
12.	+.18	-.06	-.25	-.50	.2500
13.	-.68	+.12	+.81	+.56	.3100
14.	+.43	-.56	-1.00	-1.25	1.5600
15.	00	00	00	-.25	.0625
16.	-.06	-.06	00	-.25	.0625
17.	-.25	00	+.25	00	0000
18.	+.06	-.43	-.50	-.75	.5600
19.	-.81	-.06	+.75	+.50	.2500
20.	-.06	+.25	00	00	0000
21.	-.25	00	+.25	00	0000
22.	-.25	+.25	+.50	+.25	.0625
23.	-.31	+.18	+.50	+.25	.0625
24.	-.31	+.18	+.50	+.25	.0625
25.	-.25	00	+.25	00	0000
	-5.53	+.98	+6.68		4.3794
	$\bar{X}_1$=-.22	$\bar{X}_2$=+.04	$\bar{d}$=+.25		

TABLE II

$$S = \sqrt{\frac{(d-\bar{d})^2}{N-1}}$$

$$S = \sqrt{\frac{4.3794}{24}} = \sqrt{.182} = .427$$

$$S_{\bar{d}} = \frac{S}{\sqrt{N}}$$

$$S_{\bar{d}} = \frac{.427}{\sqrt{25}} = .085$$

$$T = \frac{\bar{d}-(u-u_2)}{S_{\bar{d}}}$$

$$T = \frac{.25}{.085} = 2.90$$

$T_{.95}$ and 24 degrees of freedom = 1.711

$-1.711 \leq 2.900 \leq +1.711$ Therefore, reject H_o and accept H_A.

An example of the determination of the standard deviation, using +14A minimum pupil is as follows:

$$\text{Standard deviation} = \sqrt{\frac{X^2 - (X)^2}{N(N-1)}}$$

$$= \sqrt{\frac{2.984 - (6.87)^2}{25(24)}}$$

$$= .270$$

The results of T-tests and standard deviations for all data listed below in Table III and Table IV were arrived at in the same manner.

	Std. Dev.	Mean
+14A Min. pupil	.270	-.220
+14A Med. pupil	.107	+.040
+14A Max. pupil	.208	+.168
+14B Min. pupil	.223	-.130
+14B Med. pupil	.198	+.030
+14B Max. pupil	.171	+.100
-14B Min. pupil	.675	-.055
-14B Med. pupil	.146	-.005
-14B Max. pupil	.189	+.040

TABLE III

Comparison between	T-test
+14A Min. and +14A Med.	2.90
+14A Med. and +14A Max.	1.79
+14A Min. and +14A Max.	3.83
+14B Min. and +14B Med.	1.80
+14B Med. and +14B Max.	0.96
+14B Min. and +14B Max.	3.11
-14B Min. and -14B Med.	0.74
-14B Med. and -14B Max.	0.51
-14B Min. and -14B Max.	0.91

TABLE IV

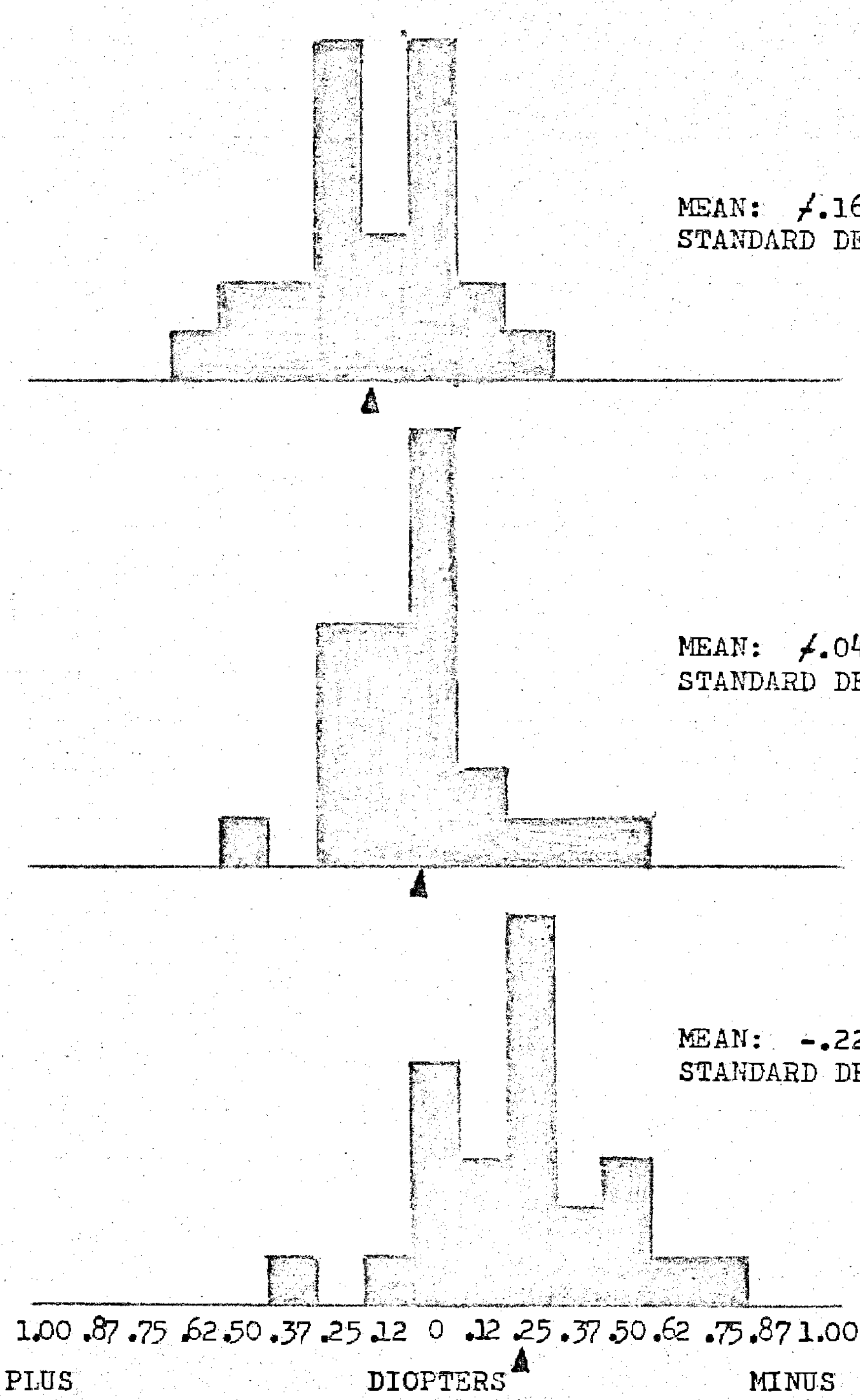
Below, in Table V, are listed the means and standard deviations of the extreme pupil sizes.

	Std. Dev.	Mean
+14A Min. pupil	.080	-.022
+14A Med. pupil	.040	-.075
+14A Max. pupil	.080	+.110
+14B Min. pupil	.108	+.005
+14B Med. pupil	.070	+.025
+14B Max. pupil	.077	-.040
-14B Min. pupil	.095	+.040
-14B Med. pupil	.031	-.067
-14B Max. pupil	.067	+.042

TABLE V

GRAPH I

14A PLUS PRE-SET
FREQUENCY DISTRIBUTION



MAXIMUM PUPIL

MEAN: ≠.168
STANDARD DEVIATION: .208

MEDIUM PUPIL

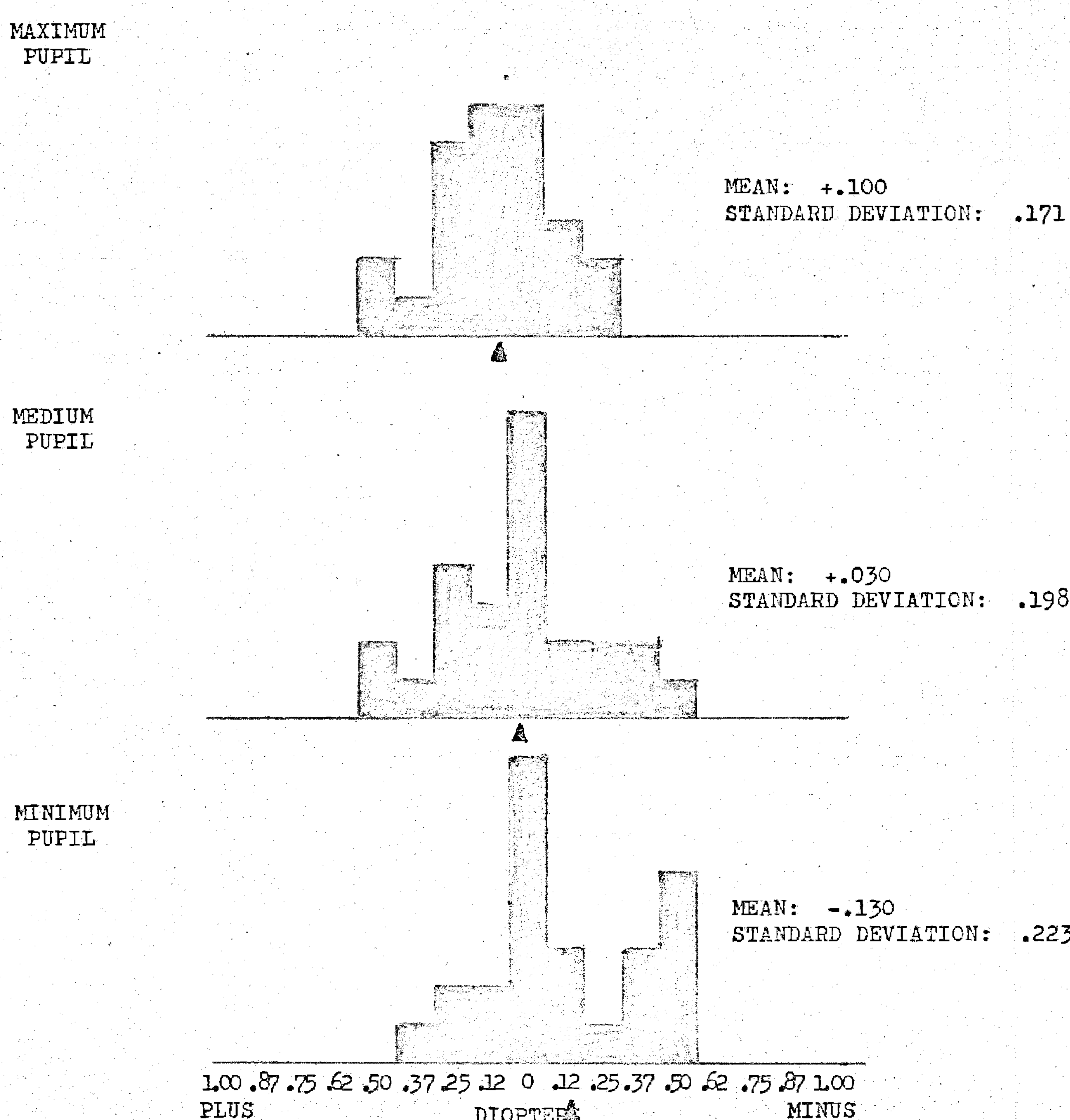
MEAN: ≠.040
STANDARD DEVIATION: .107

MINIMUM PUPIL

MEAN: -.220
STANDARD DEVIATION: .270

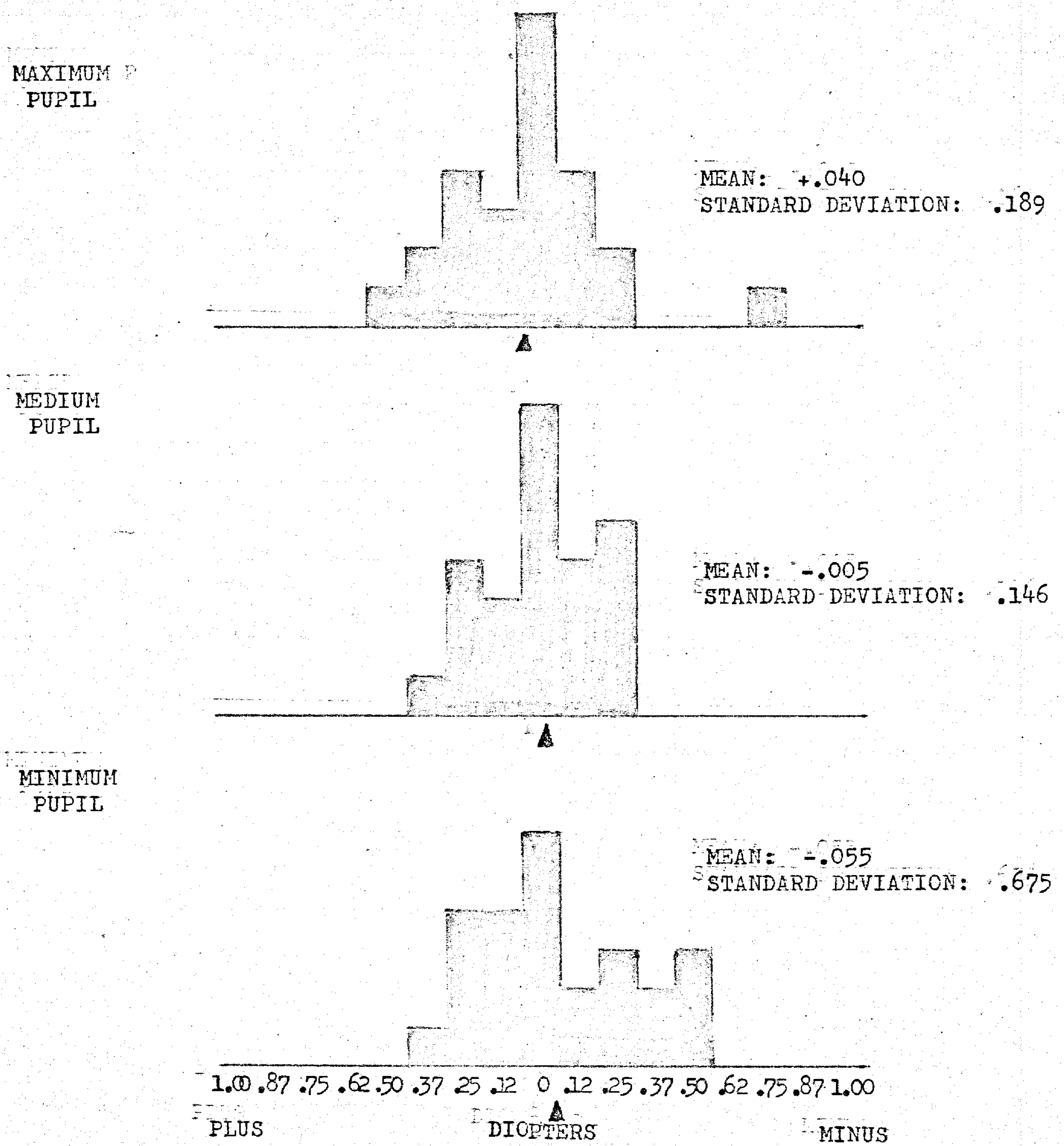
GRAPH II

14[B] PLUS PRE-SET
FREQUENCY DISTRIBUTION



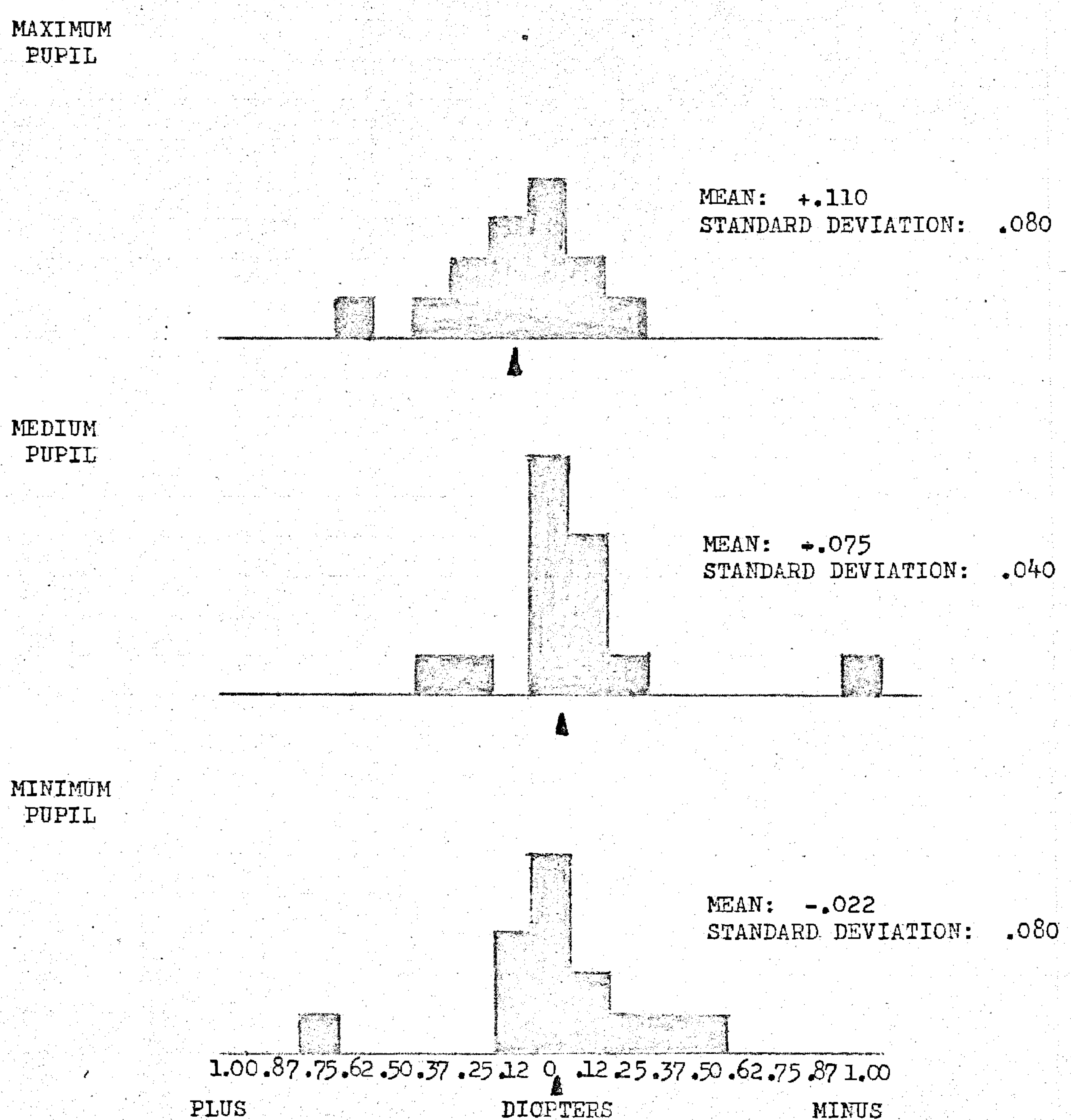
GRAPH III

14B MINUS PRE-SET
FREQUENCY DISTRIBUTION



GRAPH IV

14A PLUS PRE-SET
FREQUENCY DISTRIBUTION
EXTREME PUPIL SIZES

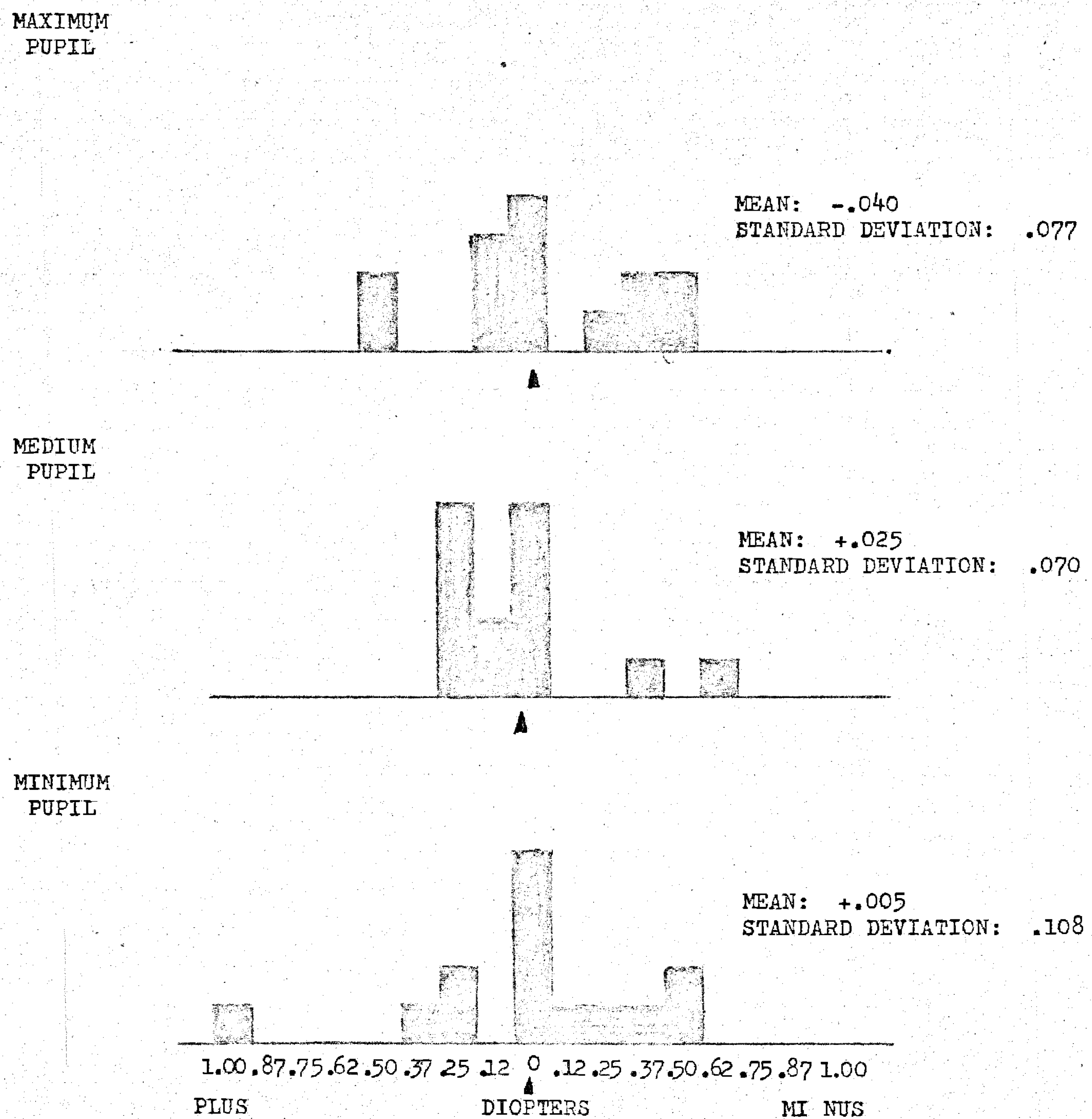


GRAPH V

14B PLUS PRE-SET

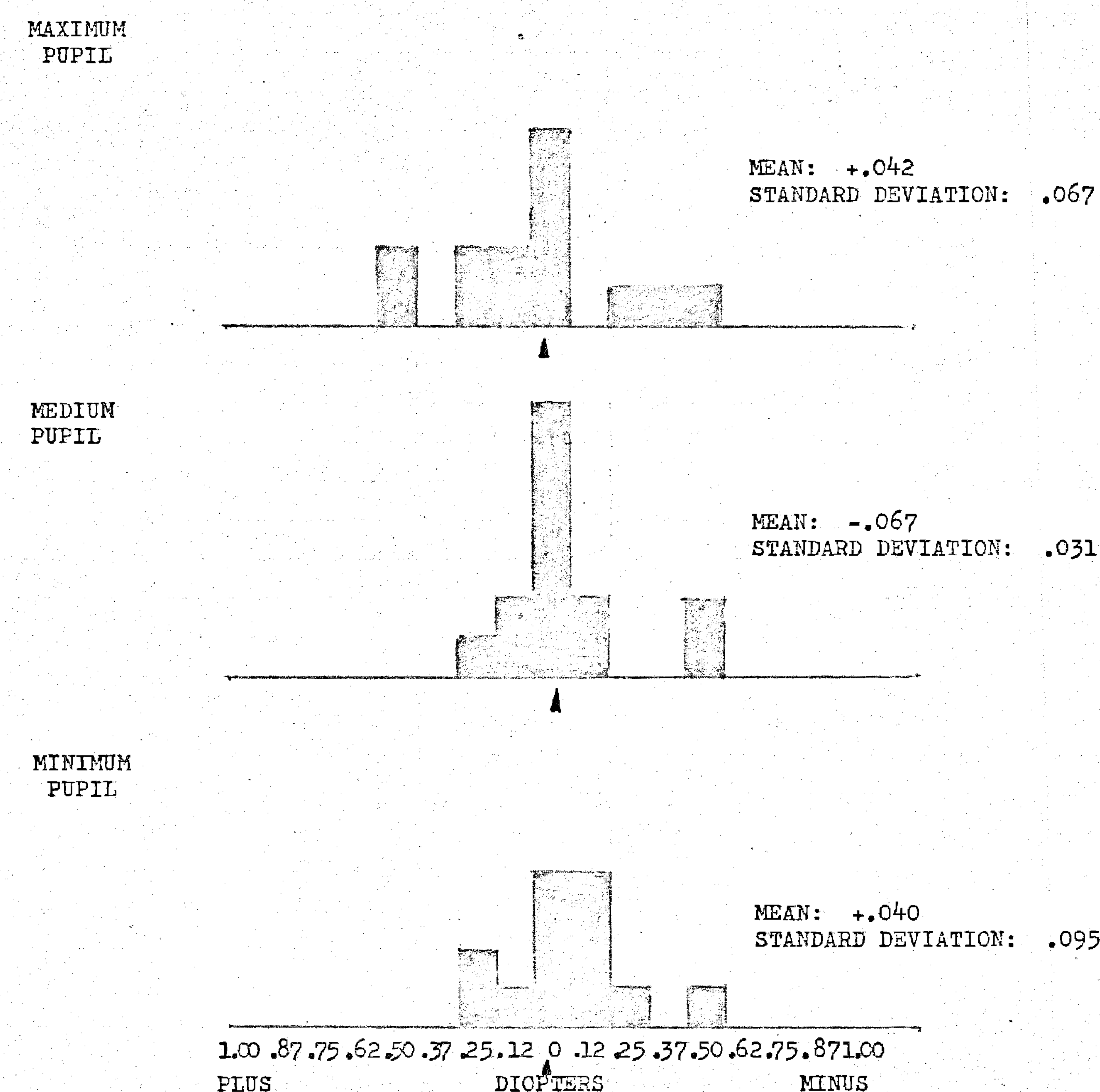
FREQUENCY DISTRIBUTION

EXTREME PUPIL SIZES



GRAPH VI

14B MINUS PRE-SET
FREQUENCY DISTRIBUTION
EXTREME PUPIL SIZES



CONCLUSIONS

From the results, many comparisons can be made and conclusions drawn. The pupil size may be a clinically important factor in nearpoint testing. The inference from this being that the illumination should be controlled since it is the prime factor in the variation of pupil size.

Within the controlled group there is a general increase in plus throughout the entire 14A, 14B complex with an increase in pupil size. This is most significantly shown in the 14A plus pre-set tests. Our measurements indicate a .25 diopter increase in plus required from minimum pupil size to medium pupil size, with an overall increase of .37 diopter from minimum to maximum pupil size. The 14B plus pre-set and 14B minus pre-set did not exhibit such a marked change. The 14B plus pre-set showed a change of slightly more than.12 diopter variation between minimum pupil size and medium pupil size. A .25 diopter change was measured between minimum and maximum pupil size. The 14B minus pre-set was even less significant, yielding slightly less than an eighth diopter change between minimum and maximum pupil size.

A possible reason that less plus is required on 14B plus and minus pre-sets as compared to the 14A plus pre-set is the effect of convergence on the accommodative system. In the binocular state, the convergence affects the accommodative system so as to move it closer toward the fixation plane.

As an exemplification of the above, we noted that as we decreased pupil size by varying illumination, less plus was needed to elicit a response, showing a greater stimulation of accommodation present. We also think that this might account for our finding less change when coming from the minus pre-set because the accommodative system is already stimulated in that case as opposed to the inhibitive state of accommodation when using a plus pre-set.

This agrees with Kepps, et al. (1962)[1] who studied the effect of pupil size on accommodation. He found that with a very small pupil, a large change in stimulus was necessary to produce a change in response.

The results from the extreme pupil groups are even less consistent. Being that the measurements taken on the extreme pupil sizes differed from the average group, we have to eliminate the extremes from the conclusions made above. This indicates that illumination alone cannot account for our findings. Clinically, we would assume that people who have extreme pupil sizes would not show the same trends shown in this experiment.

Throughout our entire testing, the most consistent results were shown when testing at the medium pupil level. This was true in both the control group and the extreme pupil size group. Standard deviations showed substantially less variance with medium pupils, inicating that the subject's response is much more consisent at this level.

Therefore, clinically, we suggest that nearpoint testing be conducted at a moderate room illumination as opposed to a very high or very low room illumination. This is substantiated by both Giles (1965) and Ferree-Rand (1934)[2].

BIBLIOGRAPHY

1. Clinical Refraction by Irvin M. Borish, O.D., D.O.S., LL.D. and The Division of Optometry, Indiana University, Third Edition, The Professional Press, Inc., Chicago, Illinois, 1970, p. 158.

2. Clinical Refraction by Borish, Third Edition, p. 357.

RECOMMENDATIONS FOR FURTHER TESTING

1. Similar tests conducted on presbyopes to determine if the same results are attainable on a group who requires considerably more illumination for near point testing.
2. More accurate measurement of pupil sizes, possibly using a subjective method such as Allens Entoptic Pupillometer in conjunction with an objective measurement.
3. Testing utilizing longer adaptation time for lower illuminations. This may have merit since maximum retinal sensitivity, according to Ferree-Rand, does not occur until 15 minutes adaptation time.