(NASA-TM-86492) TEST AND EVALUATION OF THE 2.4-MICRON PHOTOREFRACTOR OCULAR SCREENING SYSTEM (NASA) 42 p HC A03/MF A01 CSCL 06E

N85-26115

Unclas
G3/52 14890

NASA Technical Memorandum

NASA TM - 86492

TEST AND EVALUATION OF THE 2.4-m PHOTOREFRACTOR OCULAR SCREENING SYSTEM

By John R. Richardson
Technology Utilization Office

February 1985

NASA
National Aeronautics and Space Administration
George C. Marshall Space Flight Center

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA TM-86492		

4. TITLE AND SUBTITLE

Test and Evaluation of the 2.4-m Photorefractor Ocular Screening System

5. REPORT DATE

February 1985

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

John R. Richardson

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

National Aeronautics and Space Administration
Washington, D.C. 20546

13. TYPE OF REPORT & PERIOD COVERED

Technical Memorandum

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by Technology Utilization Office.

16. ABSTRACT

This report presents a test and evaluation of an improved 2.4-m photorefractor ocular screening system, jointly developed by Medical Sciences Corporation and the Marshall Space Flight Center.

The photorefractor system works on the principal of obtaining a colored photograph of both human eyes; and, by analysis of the retinal reflex images, certain ocular defects can be detected such as refractive error, strabismus, and lens obstructions.

The 2.4-m photorefractor system uses a 35-mm camera with a telephoto lens and an electronic flash attachment. Retinal reflex images obtained from the new 2.4-m system are significantly improved over earlier systems in image quality. Other features were also improved, notably portability and reduction in mass.

A total of 706 school age children were photorefracted, 211 learning disabled and 495 middle school students. The total students having abnormal retinal reflexes were 156 or 22 percent, and 133 or 85 percent of the abnormal had refractive error indicated. Ophthalmological examination was performed on 60 of these students and refractive error was verified in 57 or 95 percent of those examined.

The new 2.4-m system has a NASA patent pending and is authorized by the FDA. It provides a reliable means of rapidly screening the eyes of children and young adults for vision problems. It is especially useful for infants and other non-communicative children who cannot be screened by the more conventional methods such as the familiar "E" chart.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Night Myopia Photorefraction Retinal Reflexes Refractive Error	Unclassified -- Unlimited

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	42	NTIS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

NOMENCLATURE

Unusual Terms

Ametropia	Disproportionate discrepancy between the size and refractive powers of the eye, such that images are not brought to a proper focus on the retina; consequently, hypermetropia, myopia, or astigmatism is produced [4].
Amblyopia	Dimness of vision without detectable organic lesion of the eye.
Anisometropia	A difference in the refractive power of the two eyes.
Astigmatism	Unequal curvature of the refractive surfaces of the eye as a result of which a ray of light is not sharply focused on the retina but is spread over a more or less diffuse area.
Cornea	The transparent structure forming the anterior part of the fibrous tunic of the eye.
Cycloplegia	Paralysis of the ciliary muscle; paralysis of accommodation.
Cycloplegic	An agent that causes cycloplegia.
Dilate	To enlarge or expatiate.
Diopter	The refractive power of a lens with a focal distance of one meter; assumed as a unit of measurement for refractive power.
Emmetropia	A state of proper correlation between the refractive system of the eye and the axial length of the eyeball, rays of light entering the eye parallel to the optic axis being brought to a focus exactly on the retina. Emmetrope-An individual who has no refractive error of vision.
Esotropia	Strabismus in which there is manifest deviation of the visual axis of an eye toward that of the other eye.
Exotropia	Strabismus in which there is permanent deviation of the visual axis of one eye away from that of the other.
Hyperopia	That error of refraction in which rays of light entering the eye parallel to the optic axis are brought to a focus behind the retina, as a result of the eyeball being too short from front to back (farsightedness).
Iris	The circular pigmented membrane behind the cornea perforated by the pupil; the most anterior portion of the vascular tunic of the eye, it is made up of a flat bar of circular muscular fibers by which the pupil is dilated.
Mydriatic	Dilating the pupil. Any drug that dilates the pupil.

Myopia	That error of refraction in which rays of light entering the eye parallel to the optic axis are brought to a focus in front of the retina, as a result of the eyeball being too long from front to back (nearsightedness).
Ophthalmologist	A physician who specializes in the diagnosis and medical and surgical treatment of diseases and defects of the eye and related structures.
Ptosis	1. Prolapse of an organ or part. 2. Drooping of the upper eyelid from paralysis of the third nerve or from sympathetic innervation.
Refraction	The act or process of refracting; specifically the determination of the refractive errors of the eye and their correction by glasses.
Retina	The innermost of the three tunics of the eyeball, surrounding the vitreous body and continuous posteriorly with the optic nerve.
Retinoscopy	An objective method for investigating, diagnosing, and evaluating refractive errors of the eye, by projection of a beam of light into the eye and observation of the movement of the illuminated area on the retina surface and the refraction by the eye of the emergent rays.
Sclera	The tough white outer coat of the eyeball, covering approximately the posterior five-sixths of its surface.
Strabismus	Deviation of the eye which a patient cannot overcome. The visual axes assume a position relative to each other different from that required by the physiological conditions.

Nonstandard Abbreviations

D	Diopters of refractive errors
GRRIS	Generated retinal reflex image system
LCD	Liquid crystal diode
LD	Learning disabled students
LED	Light emitting diode
OD	Right eye
OS	Left eye
PL	Plano (no refractive error)
U	Both eyes
WL	Westlawn Middle School

TECHNICAL MEMORANDUM

TEST AND EVALUATION OF THE 2.4-m PHOTOREFRACTOR OCULAR SCREENING SYSTEM

I. INTRODUCTION

The 2.4-m photorefractor system was developed through a joint NASA-MSFC and industry Technology Utilization Application Engineering Project. The purpose of the project was to develop a reliable, low-cost photorefractor system for the early detection of multiple eye abnormalities such as (1) detecting refractive errors, (2) determining the difference in refractive error between two eyes, (3) detecting lens obstructions, and (4) determining eye alignment defects.

The photorefractor basically consists of a 35 mm camera body, a telephoto lens, and an electronic flash. Photographs are made of the subject's eyes and the resulting eye images are analyzed for ocular abnormalities.

Two earlier prototypes, a 5.5 m and a 4.2 m system, were developed and tested on 2,570 children ranging in age from 6 months to 19 years old. The 4.2-m system was also evaluated by Dr. Anthony M. Norcia and Dr. Karla Zadnik (MD) of the Smith-Kettlewell Eye Research Foundation in San Francisco, and the 4.2-m system was able to detect 88 percent of abnormalities found by using conventional retinoscopy methods as shown in Reference 1. The 4.2-m system had several areas that needed improvement and/or optimization, such as image quality, threshold sensitivity, and portability.

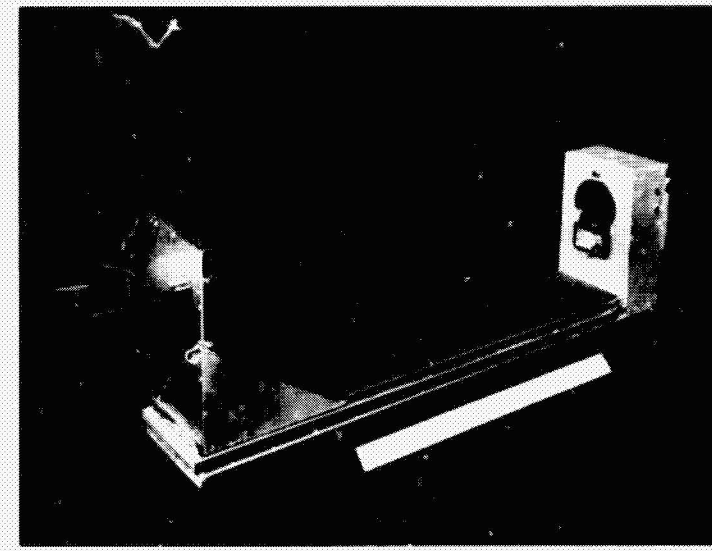
These areas of concern were resolved in development of the 2.4-m system. By reducing the length from 4.2 m to 2.4 m and using aluminum sheet material, the mass was reduced from 46 kg to less than 9 kg. Significant improvement in image quality was obtained by using a new 500-mm tele-macro lens that is capable of focusing down to 2.4 m. The 2.4-m system would allow screening to be accomplished in a smaller area than the previous system; in addition, its relatively short length would be adaptable to a mobile vehicle. Threshold sensitivity data was obtained on 60 subjects that were examined by Robert S. Moorman, Jr., MD, a local ophthalmologist.

The 2.4-m photorefractor system (Fig. 1) was fabricated on a cost-sharing contract NAS8-35828 with Electro Optical Instruments Inc. (EOI), of Wedowee, Alabama.

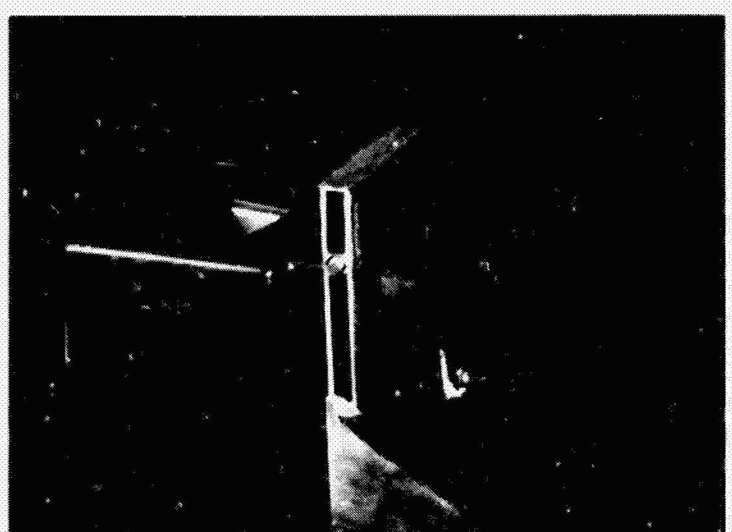
A total of 706 school age children, ranging in age from 6 to 15 years old, were photorefracted with the new 2.4-m system. It was noted from the parental permission forms that 40 percent of these children never had a formal examination as would be administered by an optometrist or an ophthalmologist. 211 of the children were learning disabled students that are involved in a Developmental Learning Program at the University of Alabama in Huntsville under the direction of Dr. Rhoda Wharry. 495 of the children were from the Westlawn Middle School and were photorefracted as part of an MSFC Technology Utilization Office participating in the NASA Partnership in Education Program that was conducted in April 1984.

Photorefraction was performed by EOI. Film processing was performed by the MSFC Photographic Branch. Image analysis was performed by Dr. J. H. Kerr, President of EOI, and the author.

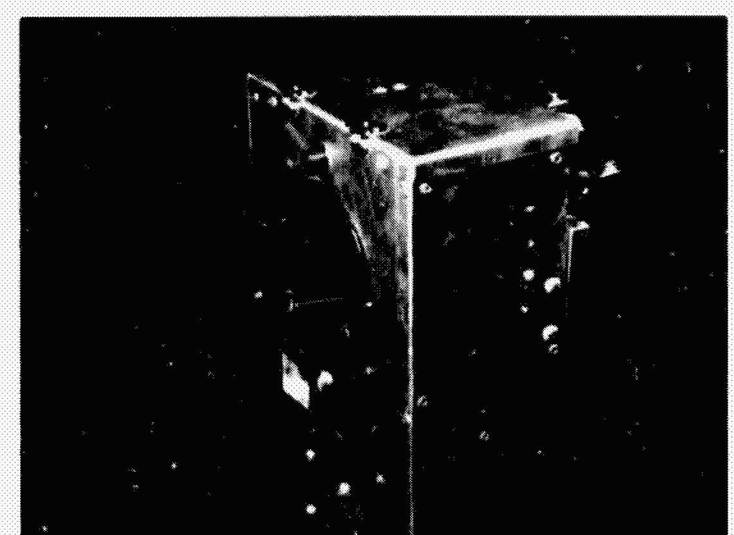
OPEN



FOLDED



HEAC POSITIONING STATION



CAMERA STATION

Figure 1. 2.4-m photorefractor ocular screening system.

II. PRINCIPLES OF OPERATION

The human visual system operates on the same principle as a conventional camera system, both having similar components. The retina of the human eye corresponds to the film plane in the camera. Both have a lens system, the camera lens is focused manually, and the eye lens is automatically focused by the ciliary muscle. The amount of light entering the lens is controlled by the aperture in the camera lens, and by the iris in the human eye. The ocular screening system is an instrument capable of testing the human eye system for defects in the retina or lens, and obstruction in the cornea, anterior chamber, or lens. This is accomplished by making a color photograph of the human eye system. Ocular alignment problems are detected by photographing both eyes simultaneously. The color images of each eye are analyzed for optical or obstruction defects, and both eyes are examined for alignment defects and differences between each eye. Use of color film is critical to the following: (1) detecting minimal refractive errors, (2) determining the difference in refractive error between two eyes, (3) detecting lens obstructions, and (4) determining eye alignment defects.

The photorefractor works in principle [1] much like a retinoscope. "It analyzes the retinal reflex produced by an off-axis light source to determine whether an eye is emmetropic or ametropic. In the case of the emmetrope, when light reflecting off the retina is considered as a point source, light rays emerge parallel from the pupil, and do not go directly through the camera aperture. This results in the diffuse red appearance of the pupil in a GRRIS photograph of an emmetrope (Fig. 2a).

For the ametrope, light coming from an off-axis retinal point source emerges divergent for the hyperope and convergent for the myope. In the hyperopic eye, the light rays from the top of the pupil pass through the camera's aperture unattenuated, and the upper part of the pupil appears brighter in the photograph (Fig. 2c).

In the myopic eye, light coming off the retina focuses at some point between the eye and the camera (determined by the magnitude of the myopia), and the resultant image is inverted. The light rays from the bottom of the pupil pass through the camera's aperture, and the lower part of the pupil is brighter than the rest of the retinal reflex (Fig. 2b)."

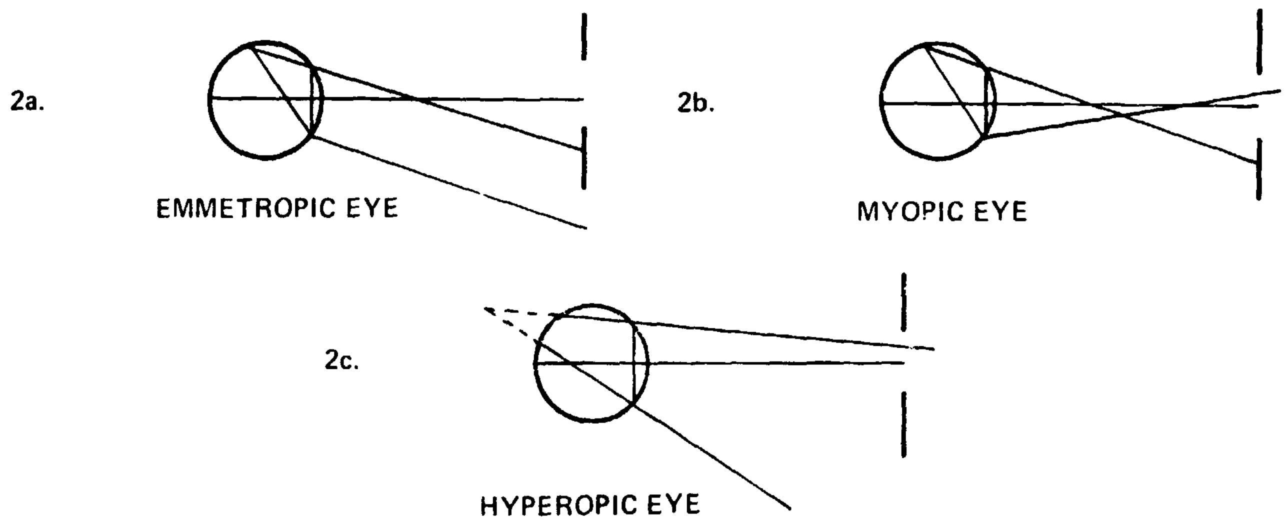


Figure 2. Schematic diagrams of off-axis photorefraction.

III. PROCEDURE

The 2.4-m photorefractor was set up in a darkened room to facilitate pupil dilation, since cycloplegic agents could not be used in the photorefraction procedure. The use of cycloplegic agents would assure optimum large and consistent pupil size; however, such agents can only be administered by a professional licensed in the use of diagnostic pharmaceutical agents. Previous testing has shown that sufficient pupil dilation can be achieved in a darkened room environment to obtain satisfactory retinal reflex images.

The students at each school were identified by a two alpha designation code for each school (WL for Westlawn) and a one to three digit number identifying a particular student. The student identification number was imprinted automatically on the color film through the use of a Kodak Data Back. The school and student identification data was entered on the parental permission form.

Retinal reflex images were recorded on Kodak VR200 color print film. The 10.2 cm x 12.7 cm color prints were used as a permanent record for comparative analysis, pupil size measurement, and the determination of ocular abnormalities. The analysis data and student identification codes were recorded and stored in a Hewlett Packard HP-75C portable computing system for subsequent data analysis and sorting.

IV. SUMMARY OF SCREENING RESULTS

A. Emmetropic Retinal Reflexes

Table 1 provides an overall summary of the Huntsville elementary school learning disabled (LD) students and the Westlawn Middle School (WL) students that were photorefracted. A total of 706 students were photorefracted, 211 LD and 495 WL students. Of the 211 LD photorefracted, 153 were considered emmetropic (75 percent), and of the 495 WL students, 397 or 80 percent were considered emmetropic. A normal or emmetropic retinal reflex, as represented by subject WL 425 (Fig. 3), has three basic characteristics: uniform retinal color between the OD and OS, a small corneal reflection (reflection of the electronic flash of the cornea) that is either centered or slightly convergent (toward the nose), and relatively uniform pupil size when comparing the OD against the OS. Blacks and Orientals generally will have darker colored, red-brown or brown, retinal reflexes.

B. Abnormal Retinal Reflexes

Apparent ophthalmological abnormalities from eye screening are shown in Table 2.

V. CORRELATION OF 2.4-m PHOTOREFRACTOR WITH RETINOSCOPY

How does the 2.4-m photorefractor compare with conventional retinoscopic techniques? To accomplish this comparison, 60 subjects, who had been photorefracted and had their refractive error determined by retinoscopy, were segregated into four groups based on the diameter of their pupils: 6 mm, 7 mm, 8 mm, and 9 mm.

TABLE 1. SUMMARY OF DATA

	Students Screened	Total Abnormal	Emmetropes
LD	211	58	153
WL	495	98	397

TABLE 2. APPARENT OPHTHALMOLOGICAL ABNORMALITIES FROM EYE SCREENING

		Percent of Referred (No. 156)	Percent of Screened (No. 706)
Functional Amblyopia	5	3.2	0.71
Position of Eyes			
Exotropia	2	1.3	0.28
Esotropia	3	1.9	0.71
Refraction			
Hyperopia	36	23.1	5.09
Myopia	97	62.3	13.74
Other Ocular Findings			
Ptosis	1	0.7	0.14
Lens Obstructions	4	2.5	0.56
Retinal Patterns	4	2.5	0.56
Pupil Size	4	2.5	0.56
Total	156	100.0	22.35

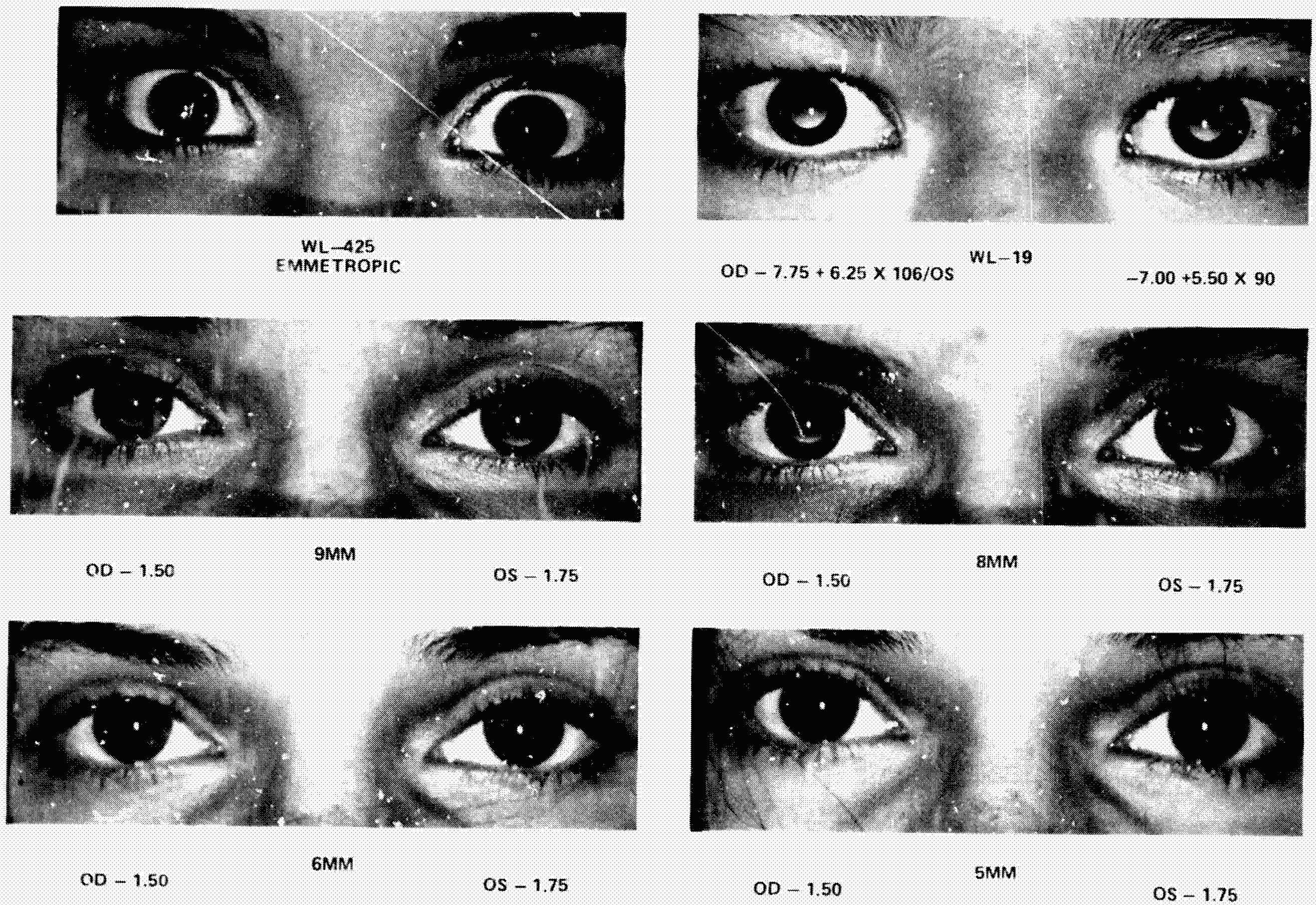


Figure 3. Emmetropic and non-emmetropic refractive error indications.

There were 13 subjects in the 6-mm group, 18 in the 7-mm group, 21 in the 8-mm group, and 8 in the 9-mm group. The two techniques, photorefraction and retinoscopy, measure the same thing — refractive error — then each technique will assign the same rank ordering for a given eye using the Spearman rank order correlation coefficient:

$$R_s = 1 - \frac{6\Sigma D^2}{n(n^2 - 1)}$$

The rank order plot for this comparison should cluster around the 1:1 diagonal. By examining the deviations from the 1:1 line, the factors that affect the accuracy of the 2.4-m photorefractor can be determined.

Two ranks were plotted for each pair of eyes, right eyes and left eyes, for each pupil size group. Hyperopes are indicated by open circles, emmetropes by open diamonds and myopes by open squares.

The rank order for the 6-mm eyes shown in Figure 4. The range of refractive error in this group of 13 eyes was from -2.5D hyperopic to +6.25D myopic for the left eyes and -3.00D hyperopic to +5.75D myopic for the right eyes. The correlation of the 2.4-m photorefractor and retinoscopy is high with no significant deviations from the 1:1 lines. The 2.4-m PR is sensitive to refractive errors, with 6-mm diameter pupils, ≥+1.00D or -1.00D and very good correlation to high refractive errors.

The rank order for the 7-mm eyes is shown in Figure 5. The range of refractive error in this group of 18 eyes was from -0.25 to -7.75D hyperopic and +100 to +4.50D myopic for the left eyes and -0.50 to -7.00D hyperopic and +0.50 to +4.00D myopic for the right eyes. The correlation of the 2.4-m PR and retinoscopy of the 7-mm eyes is starting to show some scatter from the 1:1 line. Subject WL653 (Fig. 8) was emmetropic as indicated by the open diamond, but was evaluated as a moderate myope by the 2.4-m PR. The subject was re-photorefracted and evaluated by retinoscopy and the results were the same, the 2.4-m PR indicated moderate myopia and emmetropia by retinoscopy. Subject WL653 appears to be exhibiting dark focus or night myopia.

The rank order for the 8-mm eyes is shown in Figure 6. The range of refractive error in this group of 21 pairs of eyes was from 0 to +4.75D hyperopic and 0 to -1.25D myopic for the left eyes. Thirteen of the right eyes had ≤0.5D of refractive error and 12 of the left eyes had ≤0.5D of refractive error. The correlation of the 2.4-m PR and retinoscopy of the 8-mm eyes shows significant scatter from the 1:1 line as would be predicted because of a large number of eyes with ≤0.5D refractive error. Four of the right eyes, rated as having minor or "fringe" myopia, were found to be emmetropic by retinoscopy. It should be pointed out that there is a margin of error in retinoscopy up to 0.5D. Ten of the subjects had refractive error indications that were classed as minor or "fringe" and retinoscopy indicated that none of these subjects had refractive errors exceeding 0.75D. Of the eleven subjects who had refractive errors greater than minor or "fringe," only four had refractive error >1.00D and one of those was subject WL286 (Fig. 8), which was rated as major and had +4.75D refractive error in the OS or left eye. The 2.4-m PR has the ability to detect low refractive errors with subjects having 8-mm diameter pupils, but raters will have a problem in attempting to distinguish between 0.25, 0.50, 0.75, and 1.00D

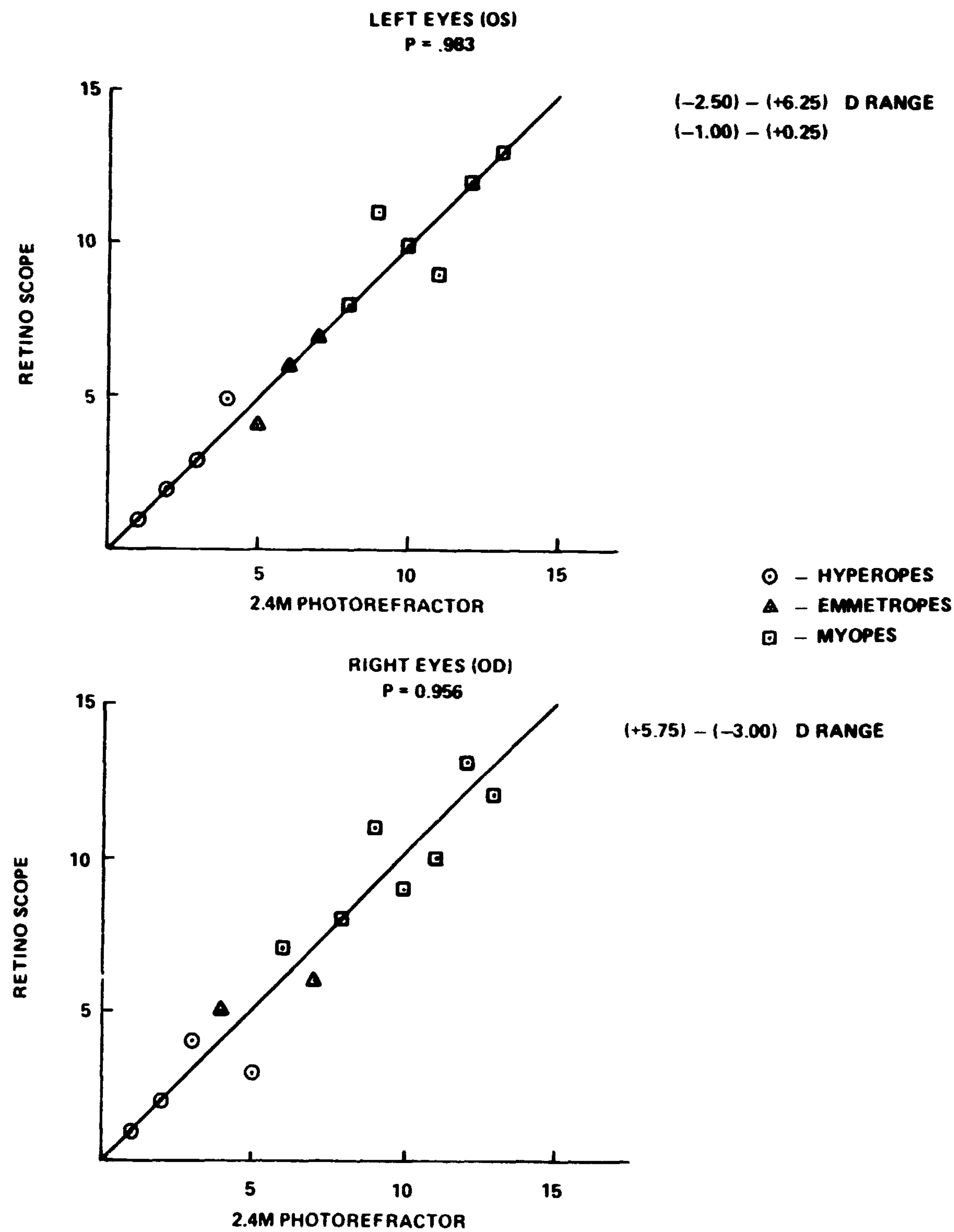


Figure 4. 6-mm pupils Spearman rank order coefficient.

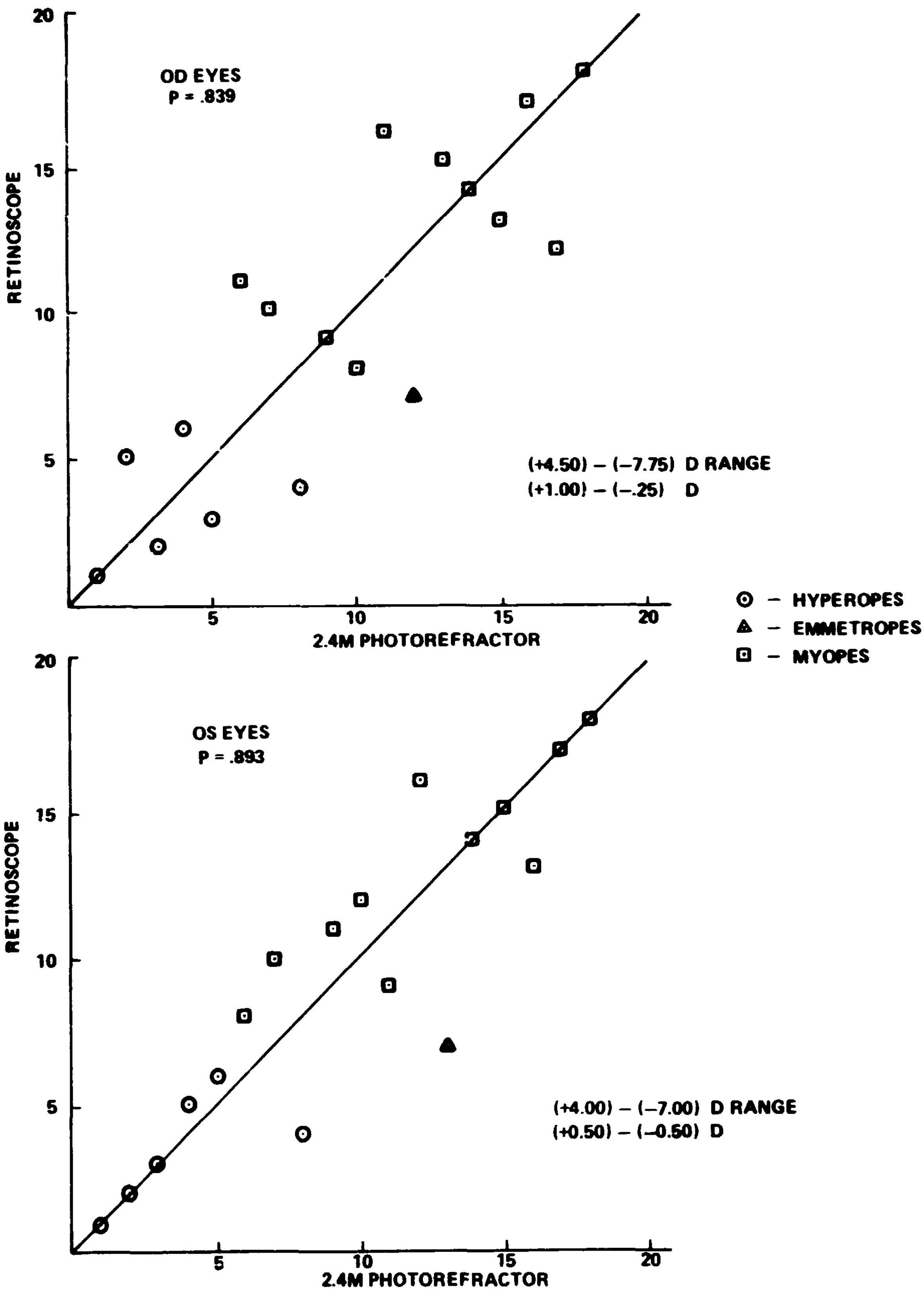


Figure 5. 7-mm pupils Spearman rank order coefficient.

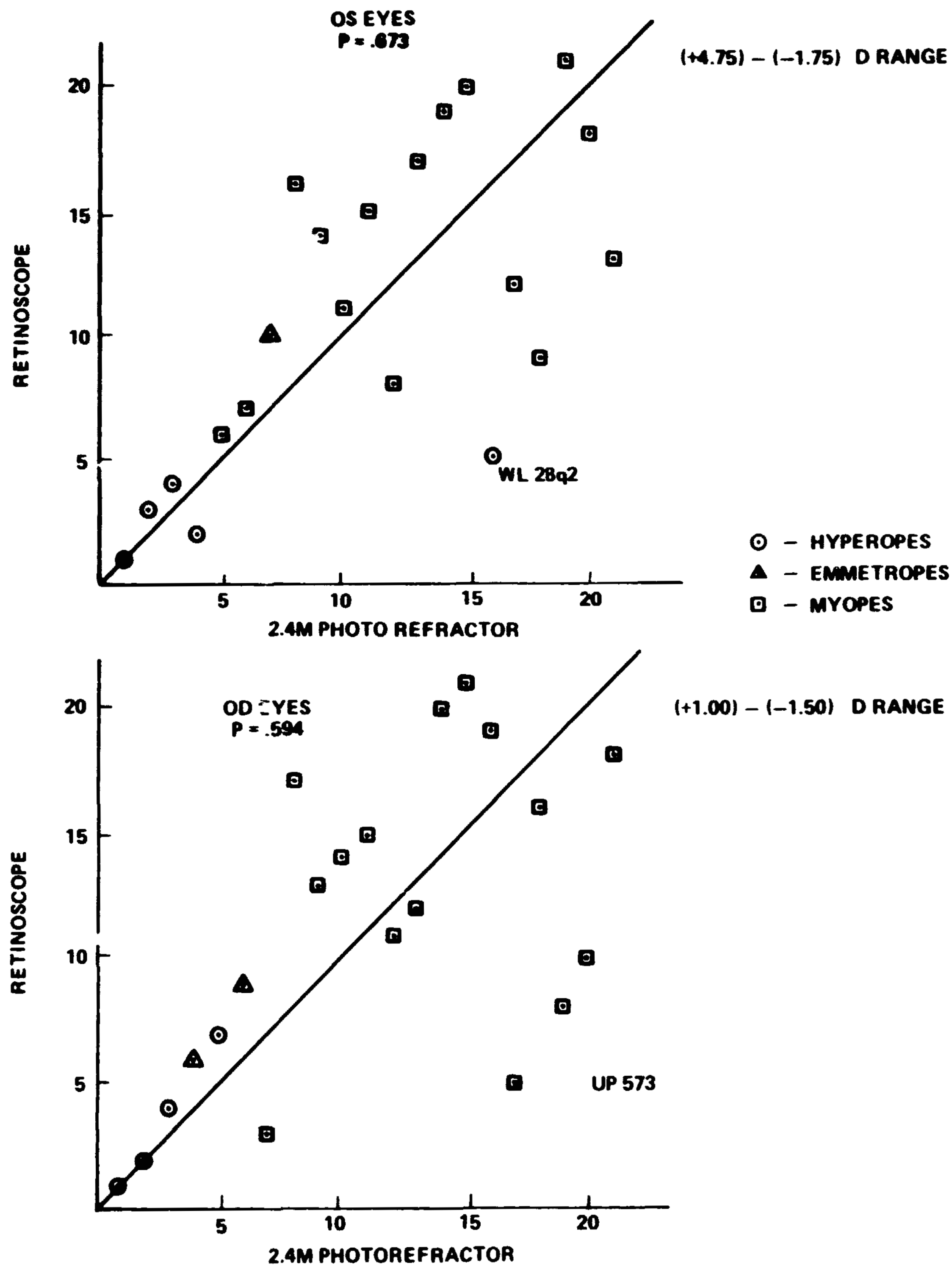


Figure 6. 8-mm pupils Spearman rank order coefficient.

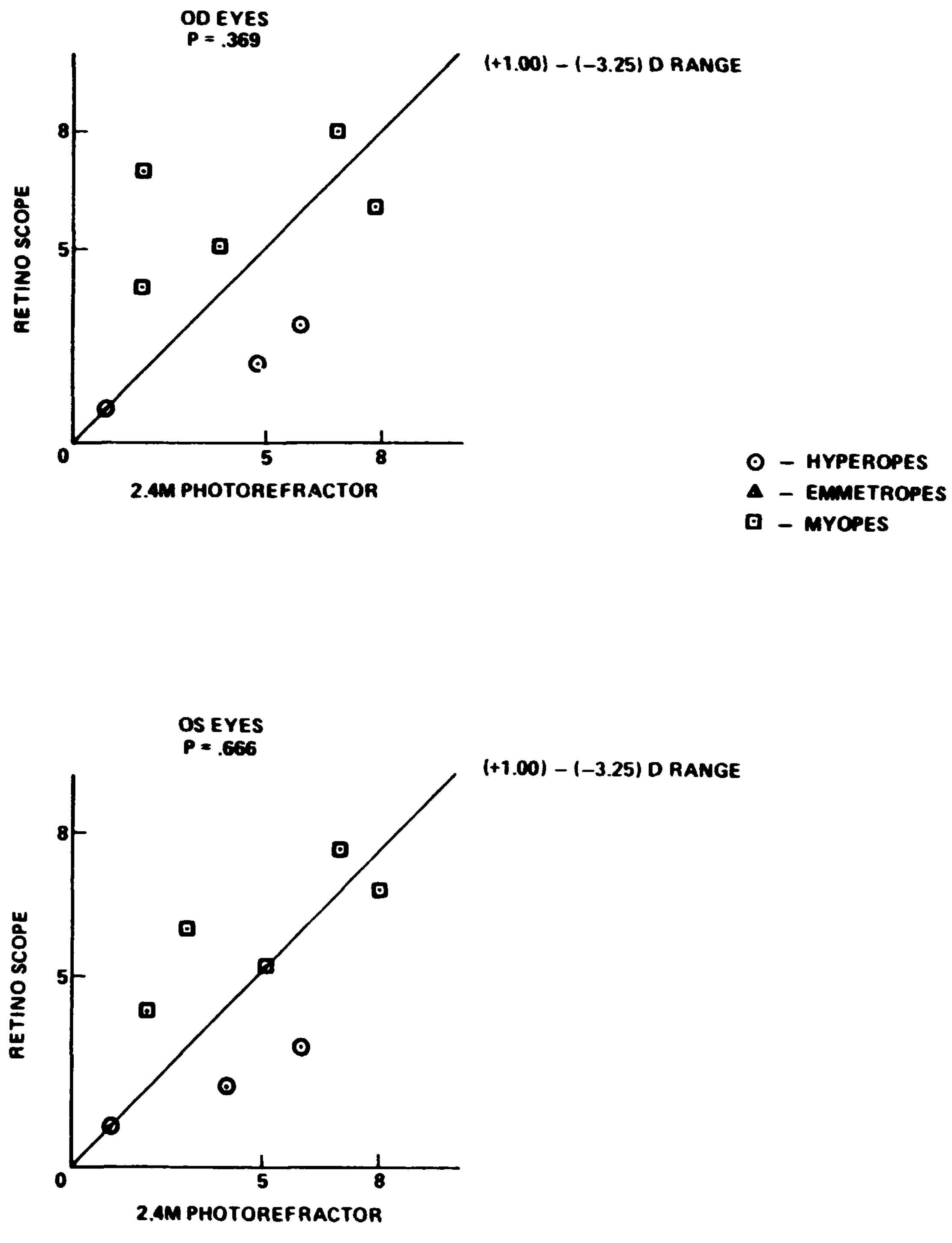


Figure 7. 9-mm pupils Spearman rank order coefficient.

of refractive error by viewing the images. Another factor affecting the refractive error indication is astigmatism which is the unequal curvature of the refractive surfaces of the eye as a result of which a ray of light is not sharply focused on the retina, but is spread over a more or less diffuse area. The amount of astigmatism and the axis on which it is located will affect the refractive error indication as displayed in the eyes.

The rank order for the 9-mm eyes is shown in Figure 7. The range of refractive error in this group of eight pairs of eyes was from +0.25 to +1.00D hyperopic and -1.00 and -3.25D myopic for left eyes and +0.25 to +1.00D hyperopic and -1.25 to -3.25 myopic for right eyes. The correlation of the 2.4 m PR and retinoscopy shows significant scatter from the 1:1 line. Two hypercpe sub;^cts (CP086, Fig. 8, and WL442) were misdiagnosed as myopes, probably night myopes. Subject WL686 was diagnosed as a major myope because the refractive error indication exceeded 50 percent retinal reflex image surface area and retinoscopy indicated -1.50D, OD, and -2.00D, OS. Subject WL140 was rated only as a moderate myope and retinoscopy indicated a -3.25D refractive error in both eyes. The large refractive error indication in subject WL686 was probably the result of night myopia reinforcing an existing moderate refractive error.

A. Summary

How does the 2.4-m PR compare with retinoscopy in the ability to rank refractive errors? Basically, the logic is that a small amount of refractive error produces a small refractive error indication in the reflex and a larger error would produce a larger refractive error indication in the reflex. The 60 subjects were ranked in groups by pupil sizes of 6 mm, 7 mm, 8 mm, and 9 mm and ranked using the Spearman rank order correlation coefficient. The rankings for the 6-mm group were high, P = 0.983 for left eyes and P = 0.956 for the right eyes as shown in Table 1. The rankings for the 7-mm group were still relatively high, P = 0.893 for the left eyes and P = 0.839 for the right eyes; however, the ranking shows a significant drop for the 8-mm and 9-mm eye groups. Part of the reason why the 8-mm ranking indicated low, P = 0.595 to P = 0.673, was due to the large number of subjects, 13 out of 21, that had refractive errors of $\leq$0.50D, and this was expected since there is no way to rank those 13 with only a 0.25D difference in refractive error. The 9-mm group also had low coefficients, P = 0.666 for left eyes and P = 0.369 for the right eyes. The rater had difficulty in ranking the eight subjects in this group because of the nonuniformity of the reflex indication. Two of the subjects (WL442, Fig. 8, and CP086) ranked as myopes were hyperopes. Subject WL388 (Fig. 9), ranked as a minor or "fringe" myope, had a refractive error of -1.25 in the OD eye and -1.00D in the OS eye which required corrective lenses. This was probably the result of active or uncontrolled accommodation (which is the ability of a person to accommodate or overcome some or all of their refractive error).

Spearman Rank Order Coefficient

Pupil Size	OS, Left Eyes	OD, Right Eyes
6 mm	0.983	0.956
7 mm	0.893	0.839
8 mm	0.673	0.594
9 mm	0.666	0.369

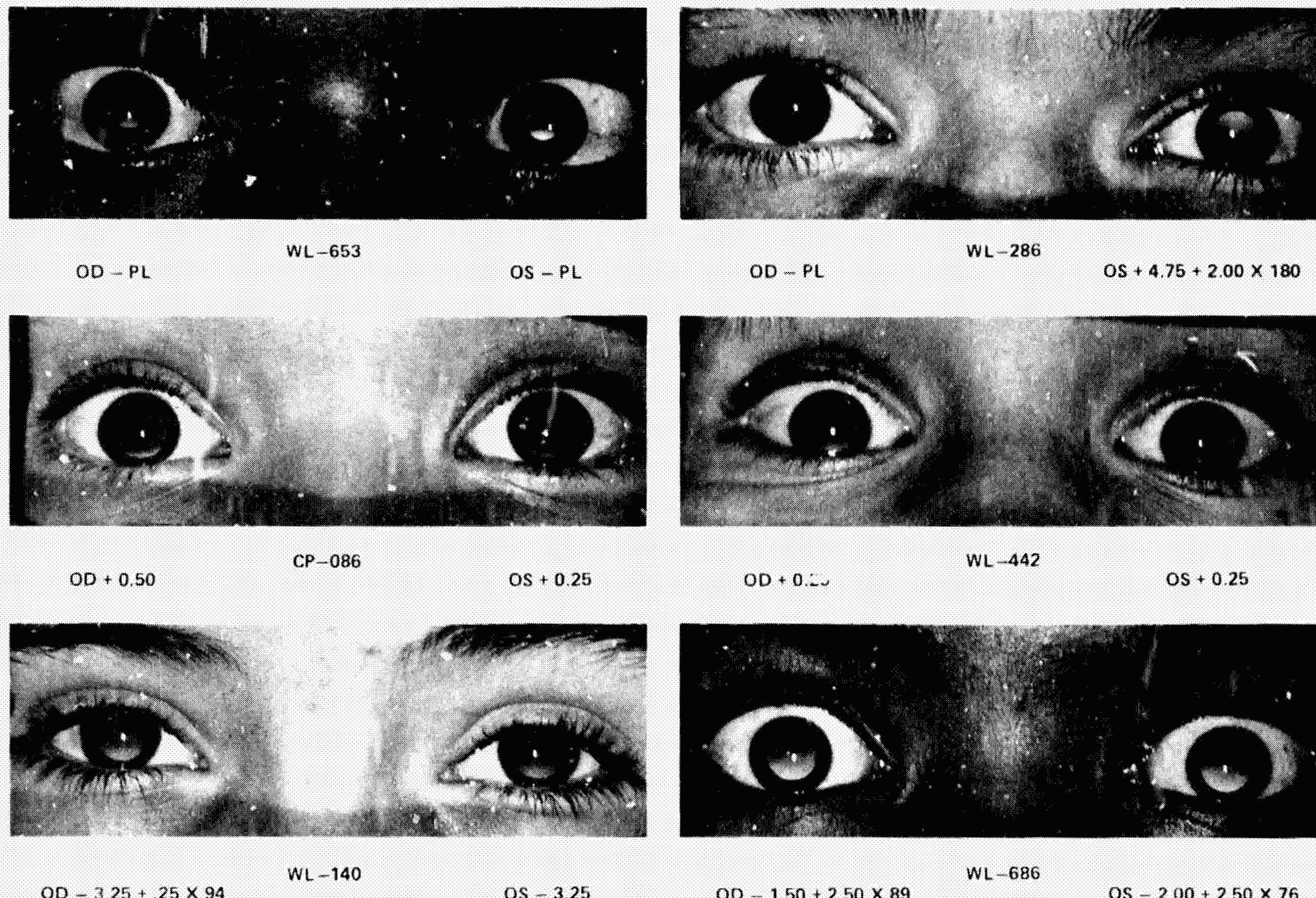
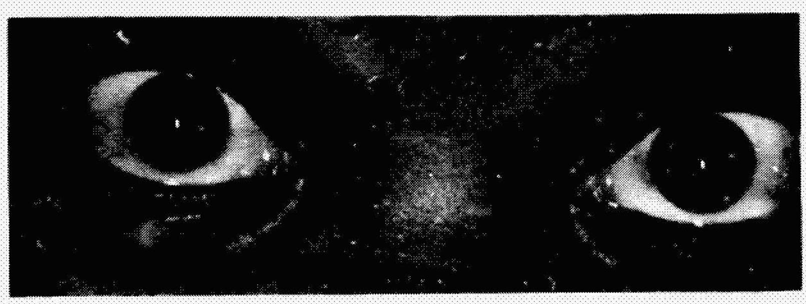


Figure 8. Refractive error indication anomalies.

WL–388

OD – 1.25 OS –1.00 +.20 X 16



WL–551

OD – PL +0.50 X 95 OS – PL +1.00 X 91

WL–470

OD – +0.50 OS – +0.50

WL–470–1

Figure 9. Refractive error indication anomalies.

The 2.4-m PR does have the capability of detecting refractive errors in the range of 0.25 to 0.50 diopters and, in most cases, discern whether or not the subjects are hyperopic or myopic, but the retinal reflex indication is perturbated by several factors such as pupil size, uncontrolled accommodation, astigmatism and night myopia. Uncontrolled accommodations and night myopia can make a significant change in the retinal reflex indication.

Night myopia impacts the photorefractor retinal reflex images in a negative manner, in that a subject can be emmetropic and indicate minor to moderate myopia after photorefraction. This would result in photorefractor data indicating refractive error and subsequent follow-up eye examinations would show the person as emmetropic.

B. Night Myopia or Dark Focus

What is night myopia and the intermediate dark focus of accommodation? "The phenomenon of night myopia, the tendency to over-accommodate for distant objects as luminance is decreased, results from the passive return of accommodation to an individually determined intermediate resting or dark focus. More generally, accommodation is viewed as a compromise between the subject's individual resting focus and the accommodative stimulus. Under optimum viewing conditions, accommodation tends to correspond to the distance of the stimulus, but is biased progressively toward the dark focus as the adequacy of the accommodative stimulus is degraded by decreased luminance. Control experiments suggest that optical aberrations are not major factors that contribute to this effect" [2].

Leibowitz and Owens performed several experiments concerning night myopia and dark focus. Of particular interest was the test performed on 16 subjects viewing a Lameris eye chart at a distance of 4 m or 0.25D containing nine rows of Landolt C's at two luminance levels. The high illumination level was accomplished with a slide projector, 109.6 cd/m^2, and the low level, 1.10 cd/m^2, of luminance was achieved by placing neutral density filters between the eye and the chart. The test subjects' accommodation was measured by a laser optometer. All subjects had their dark focus measured in total darkness, then with the eye-chart accommodation stimulus at the high and low luminance levels. The dark focus mean for total darkness was 1.20D and ranged from 0.37 to 2.28D, the low luminance level mean was 0.83D and ranged from 0.23D to 1.65D and the high luminance level mean was 0.72D and ranged from 0.10D to 1.28D [2].

All subjects exhibited night myopia or dark focus, even at the higher lumination level of 109.6 cd/m^2. The focusing object on the 2.4-m PR is a flashing 1 W red lamp located approximately 0.43D or 2.3 m from the subject's eyes, and the luminance level is between 1.10 cd/m^2 and 109.6 cd/m^2. The results of reported experiments indicate that the primary factor responsible for night myopia is the passive return of accommodation to the dark-focus, or resting, state. The passive return of accommodation to the dark-focus value is not restricted to reduced luminance condition. The general rule appears to be that any condition that results in a reduction of the amplitude of accommodation encourages the tendency to return to the dark focus. These would include (1) total darkness, (2) viewing an image the sharpness of which is independent of focus, coupled with small pupil size, and (3) degradation of the stimulus to accommodation either by decrease of luminance level or by use of structureless field devoid of contour or texture, i.e. empty sky or in fog or snow storm.

Two additional subjects, WL551 (Fig. 9) and WL470, appear to have exhibited dark-focus during photorefraction. Both subjects had small pupils, subject WL470 had 5-mm pupils and subject WL551 had 4-mm pupils. and both indicated moderate myopia by photorefraction. Retinoscopy indicated that subject WL551 was emmetropic and subject WL470 had +0.5D of myopia in both eyes, but should not have been visible because of the very small pupils; however, re-photorefraction of subject WL470 indicated that the subject was emmetropic which would confirm night myopia.

Less than 4 percent of the 706 subjects tested had pupil sizes smaller than 5 mm in diameter. It also appears that these subjects with small pupils may be more susceptible to dark-focus as the luminance level is low for photorefraction and the flashing red light lacks sharpness for the viewing subject. Only 27 subjects had pupil diameters of 5 mm and 21 of those indicated no refractive error by photorefraction. Of the six subjects indicating moderate to high refractive error, only three were subjected to retinoscopy and two out of those three had little or no refractive error and were considered to be night myopes. The 2.4-m PR depends on low lumination levels to achieve maximum pupil dilation without the use of mydriatic drops and the flashing 1 W red lamp is used as a focusing aid. The focusing aid does lack image sharpness and this increases the susceptibility of the subjects being photorefracted to the dark-focus phenomenon. Replacing the 1 W flashing lamp with a one or two digit 12.7-mm LED display would provide a sharper image for a subject's focusing aid, and increasing the luminance level should reduce the susceptibility to night myopia.

VI. AFFECT OF PUPIL SIZE ON REFRACTIVE ERROR INDICATION

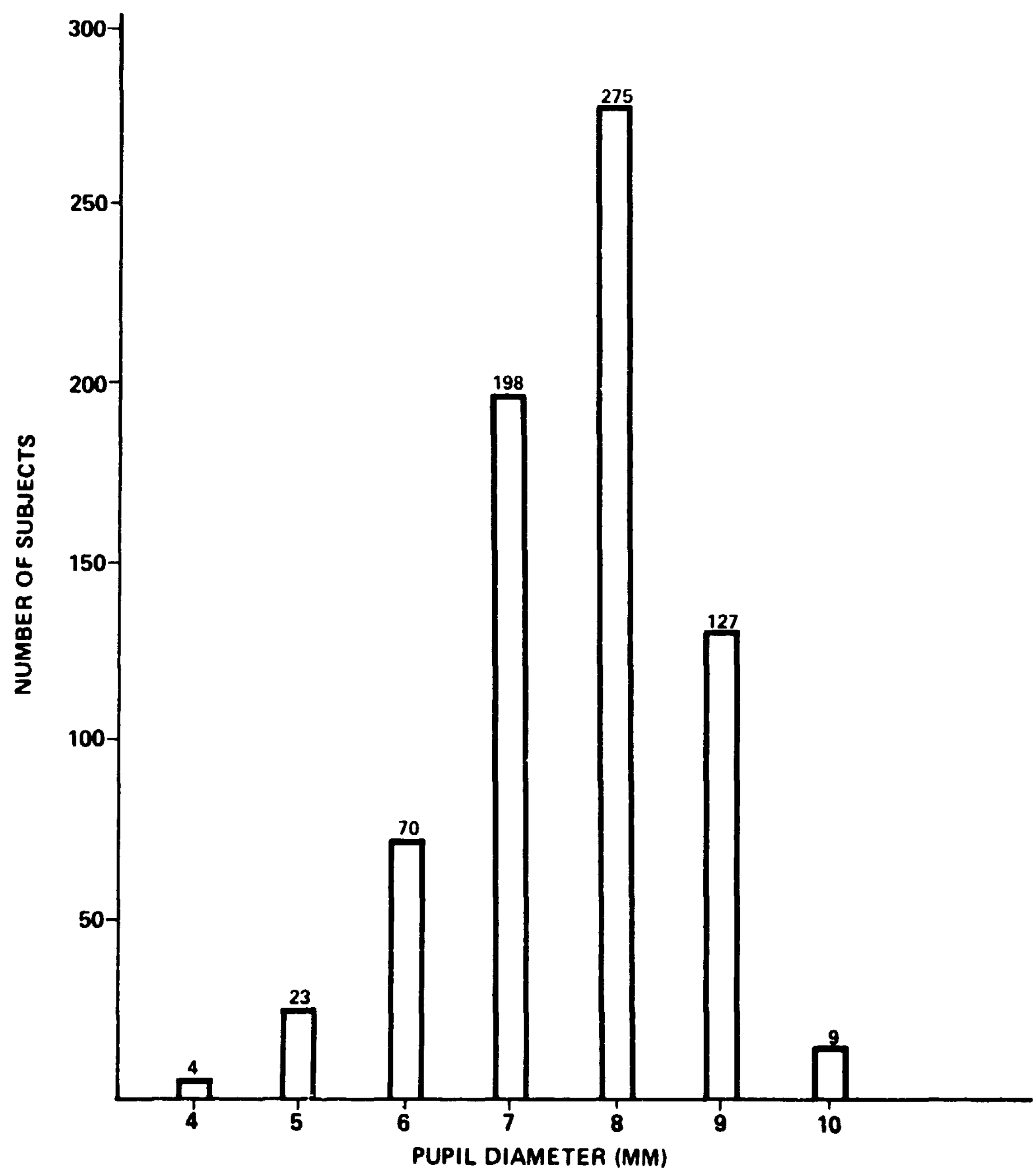
Control of pupil size is a problem for many clinical techniques and it has a major impact on the photorefraction technique. Since mydriatic drops are not used to achieve optimum pupil size (mydriatic drops can only be administered by a physician), photorefraction subjects are required to sit in a darkened room for several minutes before the photograph is taken to allow the pupils to dilate. However, this was not a major problem as the pupil size of a school age population, ages 6 through 15, tends to be relatively large.

Refractive error is manifested by a lighter color crescent located in either the upper or lower part of the fundus image (WL 19, Fig. 3). The size of the crescent is primarily dependent upon three parameters: the subject to camera film plane distance, the diameter of the pupils, and the amount of the subject's refractive error. Since the subject to camera distance is fixed at 2.4 mm, the remaining variables are pupil size and refractive error. To illustrate the effect of pupil size on the refractive error indication, a subject with -1.50D error in the OD eye and -1.75 error in the OS eye was photorefracted four times at various light levels to achieve pupil diameters from 9 mm to 5 mm (Fig. 3). A significant crescent is located at the bottom of the fundus image indicating a myopic refractive error in the 9-mm and 8-mm images. As the pupils constrict to 6 mm, a fringe crescent is barely visible at the bottom of the fundus images. The image with 5 mm diameter pipils indicates the OD eye as emmetropic and the OS eye still shows a slight fringe at the bottom. This is important information that was factored into the evaluation procedure.

Pupil sizes were determined by the following method: A test subject wore a pair of glasses with a 3.7-cm wide label taped to the front of the glasses and then was photorefracted. An enlargement was made of the negative to achieve the 3.7 cm distance of the label width on the prints. Then to provide a known reference point for all future prints, the width of the head positioning opening was measured and found to be 10 cm across that opening. All subsequent photo print processing instructions contained the 10-cm width requirement. The pupil diameters were then measured by using a circle template containing circles measuring from 2 to 12 mm in diameter. Since most of the pupils did not measure to the exact whole number, they were rounded off up or down to the nearest whole number.

Of the 706 students photorefracted, the pupil sizes ranged from 4 mm to 10 mm in diameter with 84 percent of them having pupil sizes of 7 mm or greater. The pupil size distribution is shown in Table 3.

TABLE 3. PUPIL SIZE DISTRIBUTION - LD + WL



VII. DUAL RANGE CLASSIFICATION METHOD FOR REFRACTIVE ERROR INDICATIONS

The 2.4-mm PR does detect refractive error over a broad range. Also the refractive error indication is affected by two uncontrollable variables, (1) pupil size and, to a lesser extent, (2) night myopia. The purpose of the 2.4-mm PR is screening for eye defects of which most are refractive error type defects. The 2.4-mm PR was not designed to perform the function of the retinoscope; however, the system should be capable of providing information to an analyst, and after subsequent evaluation, make a recommendation concerning the condition of the subject's eyes, whether they appear normal or emmetropic, or, if abnormal and refractive error is indicated, the severity of the indication. The refractive error data on the 60 subjects was analyzed. The refractive error ranged from +0.50D to +6.25D for hyperopes and -0.25D to -7.75D for myopes.

The ophthalmologist prescribed corrective lenses in most cases for all subjects that had refractive error ≥1D of myopic or hyperopic refractive error. The exception being young hyperopes, 3 to 6 years old. This age group has a significant number of hyperopes and clinicians rarely prescribe corrective lenses on these children unless there is an indication of high hyperopia or significant anisometropia. Most of these children grow out of this condition by the time they are 10 years old. Corrective lenses were prescribed in only one case where the subject had <1.0D of refractive error. The exception was one subject who had a -0.75D error in both eyes. This information allowed the establishment of a more definitive evaluation criteria by segregating refractive error indications >1.0D and <1.0D by the signature in the fundus reflex. The criteria used for evaluation was a "fringe", e.g. Image 6 mm (Fig. 3), crescent indication for one group and all other refractive error indications larger than the "fringe", e.g. Image 8 mm (Fig. 3), indication and which also include other refractive error anomalies, such as the diffused and fragmented patterns, were placed in the second group. The subjects were segregated first by pupil sizes 5 mm to 9 mm and then the refractive error indications were evaluated and segregated by "fringe" and greater than "fringe" as described above and compared with the refractive error verified by examination. Table 4 indicates the trend of the range of refractive error using this analysis technique.

It is apparent from Table 4 that any indication of refractive error in a 5 mm or 6 mm diameter pupil would have a refractive error of 1.00D or greater and would probably require corrective lenses. Those subjects having 7 mm diameter pupils and

TABLE 4. REFRACTIVE ERROR ANALYSIS TECHNIQUE

Pupil Diameter	Fringe Refractive Error	> Fringe Refractive Error
5	>1D	>1D
6	>1D	>1D
7	<1D	>1D
8	<0.75D	>0.5D
9	<0.75D	>0.5D

having a "fringe" or minor refractive error indication had less than 1.00D of refractive error would have a high probability that corrective lenses would not be required. Any indication greater than "fringe" or minor would indicate a refractive error greater than 1.00D and would probably require corrective lenses. The subjects having 8 mm or 9 mm diameter pupils and a "fringe" or minor refractive error indication had refractive errors less than 0.75D and would not require corrective lenses; however, those subjects indicating refractive errors slightly larger than the "fringe" or minor indication did not always exceed the 1.00D, but did exceed 0.50D.

The image evaluation system should be capable, with some degree of reliability, of segregating those subjects having less than or greater than 1.00D of indicated refractive error, when grouped by pupil sizes, 5 mm to 9 mm in diameter. The author segregated the images by pupil size groups, 5 mm to 9 mm. Then each pupil size group was segregated into two groups, "fringe" and greater than "fringe" refractive error indications. The results are shown in Tables 5 through 9. The tables also indicate whether corrective lenses were prescribed.

TABLE 5. 9-mm EYE PAIRS, REFRACTIVE ERROR INDICATIONS

	CORRECT DETERMINATIONS				INCORRECT DETERMINATIONS			
		D. MAGNITUDE				D. MAGNITUDE		
	SUBJ.	RIGHT OD	LEFT OS	COMMENTS	SUBJ.	RIGHT OD	LEFT OS	COMMENTS
REFRACTIVE ERROR INDICATIONS < 1.00 D				NONE	WL388	-1.25	-1.00	RX Significant Miss
						Insufficient Data		
REFRACTIVE ERROR INDICATIONS > 1.00 D	WL140	-3.25	-3.25	RX	CP086	+0.50	+0.25	
	MG266	+1.00	+1.75		WL442	+0.25	+0.25	
	WL342	-1.75	-2.00	RX				
	WL686	-1.50	-2.00	RX				
	WL381	-1.50	-1.50	RX				

D - DIOPTER

TABLE 6. 8-mm EYE PAIRS, REFRACTIVE ERROR INDICATIONS

	CORRECT DETERMINATIONS				INCORRECT DETERMINATIONS			
		D. MAGNITUDE				D. MAGNITUDE		
	SUBJ.	RIGHT OD	LEFT OS	COMMENTS	SUBJ.	RIGHT OD	LEFT OS	COMMENTS
REFRACTIVE ERROR INDICATIONS < 1.00 D	WL013	0	0					
	WL110	+ .75	+ .25					
	WL163	- .25	- .25					
	WI181	0	- .25					
	WL273	- .25	- .50					
	WL280	- .50	- .25					
	MG290	- .25	- .25					NONE
	WL484	- .75	- .75					
	EL513	+ .50	+ .50					
	WL552	- .50	- .75					
	WL603	0	- .25					
REFRACTIVE ERROR INDICATIONS > 1.00 D	LI108	-1.00	-1.25	RX	WL256	- .75	- .75	RX
	WL176	-1.50	-1.75	RX	WL282	+0.50	+ .70	
	WL286	0	+4.75	Amblyopia	WL352	0	- .25	
	WL460	+1.00	+ .75		DH307	+ .75	+ .75	
					CA483	+ .75	+ .50	
					UP573	+ .25	+ .75	

D - DIOPTER

TABLE 7. 7-mm EYE PAIRS, REFRACTIVE ERROR INDICATIONS

	CORRECT DETERMINATIONS				INCORRECT DETERMINATIONS			
		D. MAGNITUDE				D. MAGNITUDE		
	SUBJ.	RIGHT OD	LEFT OS	COMMENTS	SUBJ.	RIGHT OD	LEFT OS	COMMENTS
REFRACTIVE ERROR INDICATIONS < 1.00 D	LI095	- .25	- .50		WL068	+1.00	+ .75	
	WL407	- .75	- .50		WL482	-1.25	- .50	
	CA474	- .50	- .50		EC511	+3.25	+ .50	Amblyopia
REFRACTIVE ERROR INDICATIONS > 1.00 D	WL010	+4.50	+4.00	RX	WL653	0	0	Probable Night Myopia
	WL019	-7.75	-7.00	RX				
	WL232	-1.50	-1.50	RX	WL522	- .50	- .75	Probable Night Myopia
	FA233	-6.75	-6.00	RX				
	WL416	-2.25	-2.50	RX				
	WL452	+3.75	+3.75	RX				
	WL561	+3.75	+ .75	Amblyopia				
	WL566	-1.75	-1.75	RX				
	WL621	-3.50	-1.5-	Amblyopia				

D - DIOPTER

TABLE 8. 6-mm EYE PAIRS, REFRACTIVE ERROR INDICATIONS

	CORRECT DETERMINATIONS				INCORRECT DETERMINATIONS			
	SUBJ.	D. MAGNITUDE RIGHT OD	D. MAGNITUDE LEFT OS	COMMENTS	SUBJ.	D. MAGNITUDE RIGHT OD	D. MAGNITUDE LEFT OS	COMMENTS
REFRACTIVE ERROR INDICATIONS < 1.00 D	NONE				NONE			
REFRACTIVE ERROR INDICATIONS > 1.00 D	CH024	+5.75	+6.25	RX				NONE
	WL086	-1.00	-1.25	RX				
	WL126	-2.00	-2.25	RX				
	WL130	-3.00	0	Amblyopia				
	DH317	+1.25	+1.00	6 Year Old				
	WL330	-1.75	-1.25	RX				
	WL365	-1.75	-2.00	RX				
	WL404	+4.25	+3.25	RX				
	CA414	+0.25	+6.00	RX Amblyopia				
	WL440	-2.00	-2.50	RX				
	WL606	-1.00	-1.00	RX				

D - DIOPTER

TABLE 9. 5-mm EYE PAIRS, REFRACTIVE ERROR INDICATIONS

	CORRECT DETERMINATIONS				INCORRECT DETERMINATIONS			
		D. MAGNITUDE				D. MAGNITUDE		
	SUBJ.	RIGHT OD	LEFT OS	COMMENTS	SUBJ.	RIGHT OD	LEFT OS	COMMENTS
REFRACTIVE ERROR INDICATIONS < 1.00 D	NONE				NONE			
REFRACTIVE ERROR INDICATIONS > 1.00 D	WL203	3.00	3.25	RX	WL470	+.50	+.50	Probable Night Myopia**
					WL551	0	0	Probable Night Myopia**

D - DIOPTER

SUMMARY

The data in Table 10, which is a summary of Tables 5 through 9, essentially means that for those subjects having pupil diameters in the range of 7 mm to 9 mm, and exhibiting only a "fringe" of refractive error indication, there is a 79 percent chance that they would have less than 1.00D of refractive error and would probably not require corrective lenses. On those subjects indicating greater than a "fringe," fragmented or diffused refractions error indication, with any pupil size, there would be a 71 percent chance that they would have more than 1.00D of refractive error and a high probability that they would require corrective lenses. A further breakdown is shown in Table 11 and indicates that those having pupil sizes in the range of 5 mm to 6 mm and exhibiting any refractive error greater than minor or fringe would have an 85 percent chance of having >1.00D of refractive error and require corrective lenses. Those having pupil sizes in the range of 8 mm and 9 mm and exhibiting any refractive error greater than minor or fringe would have a 53 percent chance of having >1.00 of refractive error and require corrective lenses.

TABLE 10. SUMMARY OF DATA FROM TABLES 5 THROUGH 9

	Fringe <1.00D Refractive Error		Greater Than Fringe >1.00D Refractive Error	
	Correct	Incorrect	Correct	Incorrect
5 mm	—	—	1	2 *
6 mm	—	—	11	0
7 mm	3	3	9	2 *
8 mm	11	0	4	6
9 mm	0	1	5	2
Total	14	4	30	12

*Subjects probably exhibiting night myopia.

TABLE 11. PROJECTED PROBABILITIES OF REFRACTIVE ERROR >1D

Pupil Diameter	Refractive Error Indication	≥1.00 D (%)
5 mm - 6 mm	ANY	85
7 mm	Minor or Fringe	50
7 mm	>Minor or Fringe	82
8 mm - 9 mm	Minor or Fringe	10
8 mm - 9 mm	>Minor or Fringe	53

VIII. PHOTOREFRACTION OF SUBJECTS WEARING CORRECTIVE LENSES

Of the 706 subjects photorefracted, 103 or 15 percent had corrective lenses. All subjects were photorefracted with and without their corrective lenses. The purpose was to (1) determine if refractive error could be detected without their corrective lenses and (2) to determine what or if any refractive error could be detected in those subjects wearing corrective lenses.

A typical subject photorefracted with and without corrective lenses is shown in subject WL323 and WL324 (Fig. 10). Image WL323 indicates a large myopic refractive error without corrective lenses, and image WL324 does not indicate any refractive error with the subject wearing corrective lenses. Another subject, WL52 and WL53 (Image WL52), shows a large myopic refractive error; however, with corrective lenses, the subject still indicates the same minor refractive error (Image WL53). Note the fringe crescent at the bottom of the retinal reflexes.

One problem encountered while photorefracting subjects with corrective lenses was the reflection of the electronic flash off their lenses. Forty-two percent of those photorefracted with corrective lenses had reflections off of their lenses that obscured part of the retinal reflex image. The worst cases being subject WL647 (Fig. 11) and WL648. Note that image WL648 shows the flash reflection almost totally obscurring the retinal reflex images; however, in most subjects, the reflection(s) did not significantly obscure the retinal reflex image so that an analysis could be performed as to the effectiveness of the corrective lenses.

Only two subjects had contact lenses and they were only photorefracted while wearing their lenses. Note in subject WL325 (Fig. 11), the outline of the lenses is clearly visible and the correction appears to be satisfactory.

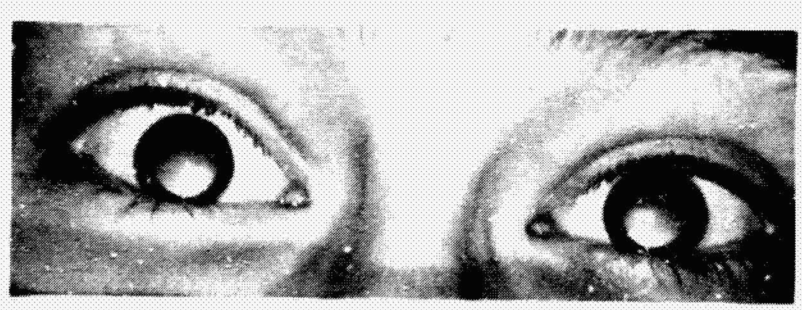
The 2.4-m PR was able to detect refractive error indications in 83 (81 percent) out of the 108 subjects that were photorefracted. Of the 20 that were missed, thirteen had pupil sizes ≤6 mm in diameter, and it would be possible that any refractive error from 0.75 to 1.25D would not be indicated in these images. The remaining seven subjects had 7-mm and 8-mm diameter pupils and refractive error should have been detected in these subjects if it existed. It is also possible that some of these subjects may have had little or no refractive error after wearing their corrective lenses for a period of time.

Retinoscopy was only performed on six of the 103 subjects. These subjects were selected because of their refractive error indications and pupil sizes, as part of the overall group that was subjected to retinoscopy to establish the data base for the 2.4-m PR. Three out of six had relatively large refractive errors in the range of 3.00D to 6.75D and two had minor refractive errors of 0.75D. One subject, WL58 (Fig. 11) and 59, with 6-mm diameter pupils did not indicate any refractive error with or without corrective lenses. Subsequent retinoscopy revealed refractive error of -1.50 + 1.00 x 169D OD and -1.25 + 1.00 x 171D OS myopic. The (+) cylindrical error is within 11 deg of the with-the-rule astigmatism (axis 180 deg). The astigmatic or cylindrical error may have impacted the spherical error which resulted in the emmetropic appearance of the subject's eyes.

The 2.4-m PR measures refractive error for the vertical meridian of the eye only and the axis of astigmatism is not readily determinable, especially for oblique and horizontal axis. However, 37 out of the 60 subjects (62 percent), that had retinoscopy performed on them, were found to have astigmatism, and seven of those had cylindrical refractive errors ≥2.00D which is considered clinically significant. "With-the-rule astigmatism (axis 180 deg) is measured as total power in the vertical meridian, while against-the-rule astigmatism (axis 90 deg) seems to be measured roughly as the equivalent sphere (half the power of the astigmatic corrections in addition to the spherical component of the refractive error). Astigmatism of the oblique orientation

WL–52

WL–53



WL–323

WL–324

Figure 10. Photorefraction with corrective lenses.

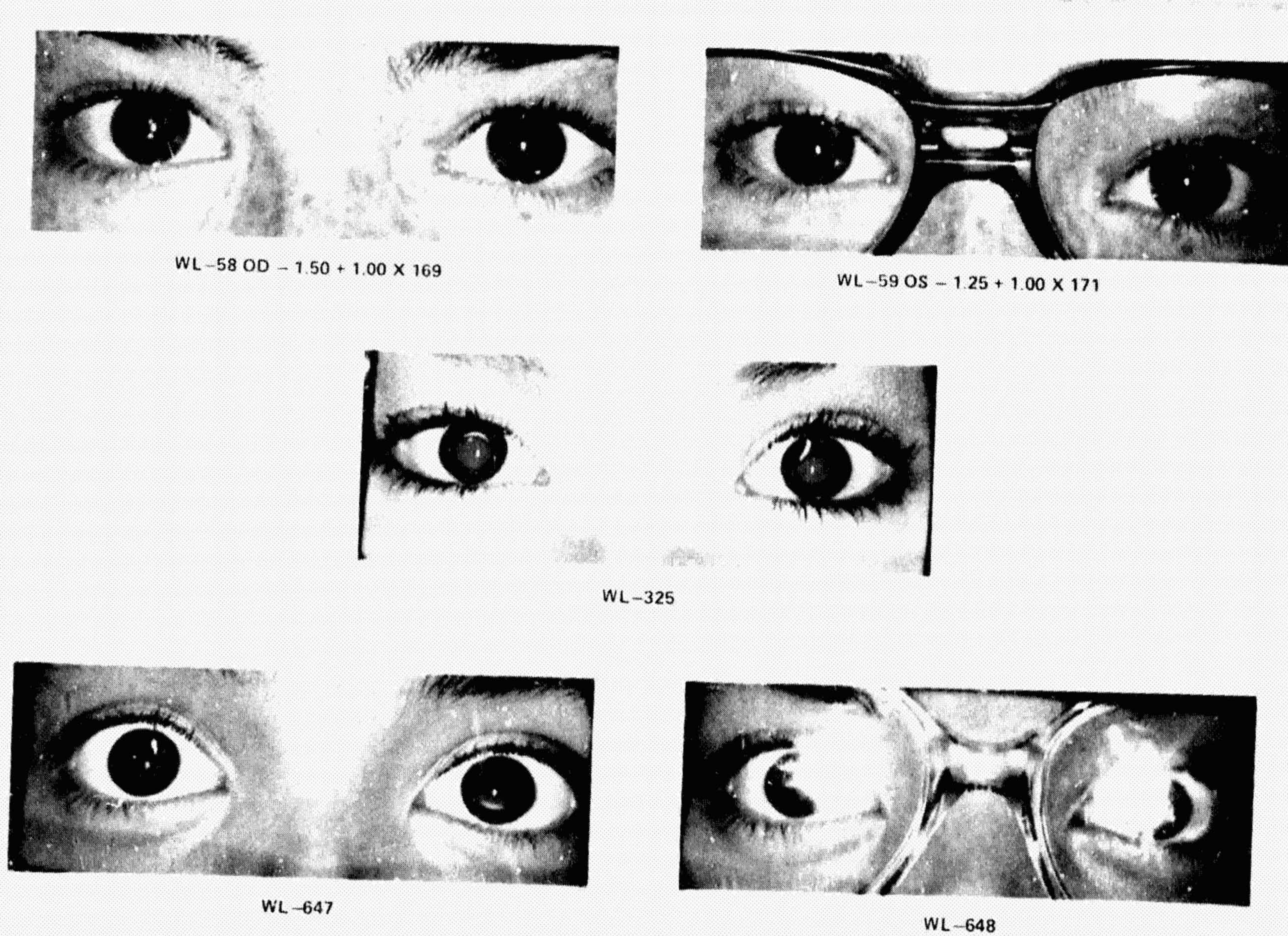


Figure 11. Photorefraction with corrective lenses.

also shows up as the spherical equivalent, but orientation is not evident. This could lead to an underestimate of moderate astigmatic errors with no accompanying spherical refractive error. For example, 2.00D of astigmatism is clinically significant. It may, however, show up as only 1.00D and perhaps be dismissed as not significant" [1].

IX. NON-AMETROPIC ANOMALIES

Non-ametropic anomalies account for only 18 (or 2.5 percent) of the total (706) tested. The breakdown of these anomalies was: strabismus (esotropia, exotropia) 5, pupil size difference 4, lens obstructions 4, retinal patterns 4, and ptosis 1.

Strabismus is essentially a deviation of the eye which a patient cannot overcome. Esotropia is a strabismus where the visual axis is toward the other eye, and exotropia where the visual axis is away from the other eye. Detection by photorefraction is dependent upon the position of the corneal reflection with respect to the iris, either centered or left or right. Since the flash is essentially a point source illumination located just below the camera lens, the corneal reflection is always located near the center of the eye on the visual axis, which is slightly toward the nose. Note the emmetropic eye (Fig. 12) just below the OD eye. The OS eye is shown as esotropic and the corneal reflection is located near the right edge of the iris (esotropic eye). Conversely, the corneal reflection is located near the left edge of the exotropic eye. Convergent and divergent strabismus, involving both eyes, is also illustrated.

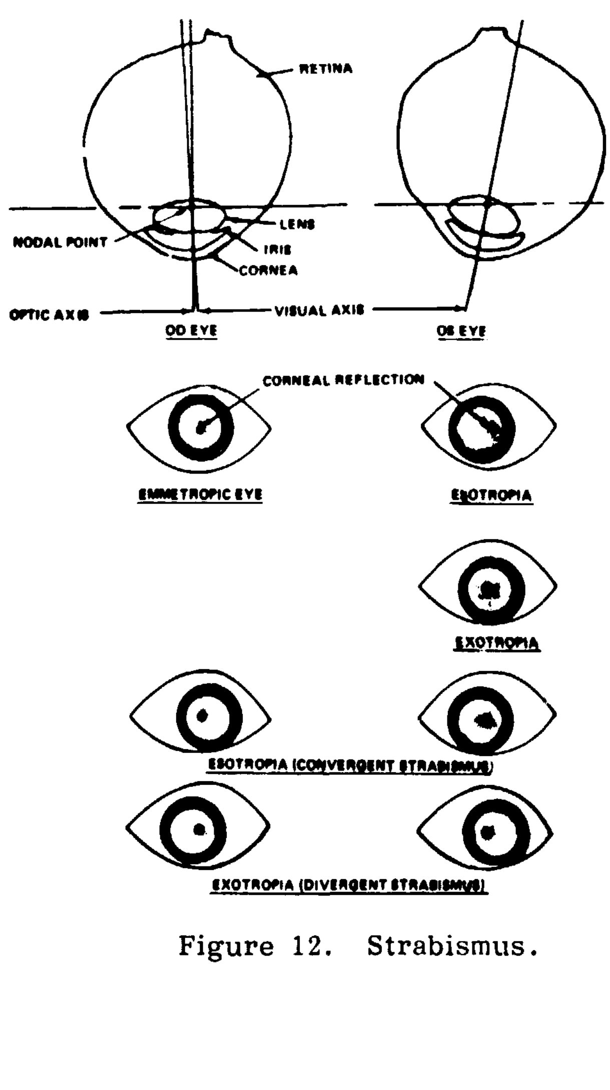


Figure 12. Strabismus.

Large angles of strabismus are relatively easy to detect. Subject MO536 (Fig. 13) has esotropia OS; notice that the corneal reflection is located on the edge of the iris. Subject MG262 has exotropia OD, and the corneal reflection is located on the inside edge of the iris. Another situation involving large angles, approximately 11 deg, strabismus is the presence of a significantly lighter retinal reflex, as noted in the OD eye of subject WL682. Kari Kaakinen [3] notes that the corneal reflection became lighter at large angles, 9 to 13 deg, of esotropia, and he speculates that this brightness may be caused by the bright reflex of the optic disc.

Subject WL586 shows a normal pair of eyes focused on the fixation light; note, corneal reflections are located slightly off-center toward the nose. In addition, the sclera (white portion of the eye located outside the iris) is relatively uniform on either side of the iris which is essentially centered in the eye opening. Subject WL582 has corneal reflections that are out of position, the corneal reflections are located in the lower right hand portion of the OD eye and centered in the lower portion of the OS eye. In addition, the iris of each eye is not centered which indicates that this subject was fixating on some point up and to the right of the blinking fixation lamp.

Another subject was photorefracted twice. The first photorefraction, WH33 (Fig. 14), appears normal; however, the second photorefraction, WH34, shows an abnormal condition, convergent strabismus (crosseyed) condition. Note the lighter colored fundus reflexes, off-set corneal reflections, and the non-uniform areas of sclera in each eye.

Lens obstructions are relatively easy to detect. Subject WL376 (Fig. 14) has a cataract in the OS eye. Note the pattern of the obstruction. Pupil size differences of less than 2 mm may not be indicative of an ocular problem; however, it could be a sign of a neurological problem. Subject WL375 has a 1.5-mm difference, 7-mm OD and 5-mm OS. Subject WL99 has a 2-mm difference, 8.5-mm OD and 6.5-mm OS. Subject WL99 should be examined by an ophthalmologist. The OS eye is 2 mm smaller in diameter than the OD eye and it is also exotropic.

X. CONCLUSIONS, SUMMARY AND RECOMMENDATIONS

A. Conclusions

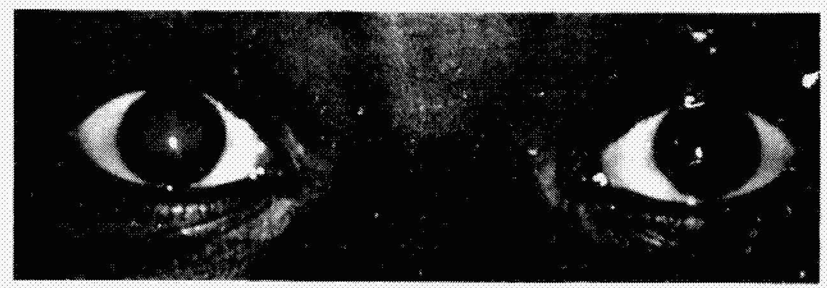
The 2.4-mm phtorefractor is an effective system for the screening of people for specific ocular abnormalities. The system is most effective on children and young adults between the ages of 1 and 20 years of age because their pupils tend to dilate in a darkened environment more readily than do adults, which is necessary to obtain a satisfactory retinal reflex image size for subsequent analysis. The system is non-evasive to the individual being tested requiring only minimal cooperation and less than 30 sec to perform the procedure.

The system is capable of detecting multiple ocular abnormalities such as (1) refractive error (hyperopia and myopia), (2) determining a difference in refractive error between two eyes (anisometropia), (3) lens obstructions (cataracts and tumors), and (4) eye alignment defects (strabismus). Sensitivity is around 0.25 to 0.50 diopters with 8-mm to 9-mm diameter pupils and decreases as pupil size decreases to around 1.00 to 1.25 diopters with 6-mm diameter pupils. The system is capable of detecting a 0.25 to 0.50 diopter difference between two eyes, anisometropia.

Figure 13. Strabismus indications.

WH–33 NORMAL

WH–34 CONVERGENT STRABISMUS



WL–99 PUPIL SIZE

WL–375 PUPIL SIZE

WL–376 CATARACT

Figure 14. Other non-ametropic anomal indications.

Large differences show up readily and the system would be beneficial in detecting refractive amblyopia in children between the ages of four months and three to four years old as they are difficult to test using routine ophthalmic examination procedures. Five amblyopia subjects were photorefracted and four out of the five had significant anisometropia which was easily detected by photorefraction. Lens obstructions, such as cataracts or tumors, are relatively easy to detect, as they are a contrasting color, such as gray or blue as compared to the red fundus reflex. The system is also capable of detecting strabismic deviations and angles in the two to three degree range; however, caution must be used during analysis for strabismic deviations, as any esotropic-exotropic combinations may be suspect as a left or right gaze by the subject being tested.

The correlation between the photorefractor and retinoscopy decreases with increasing pupil size. The logic is that a small amount of refractive error produces a small refractive error indication in the reflex and a larger error would produce a larger refractive error indication in the reflex. The author ranked 60 subjects in groups by pupil sizes of 6 mm, 7 mm, 8 mm, and 9 mm using the Spearman rank order correlation coefficient. The best correlation was ≥ 0.956 for the 6-mm eyes to a low of 0.369 for 9-mm OD eyes. The refractive error indication produced by the photorefractor is perturbated by uncontrolled variables such as astigmatism, uncontrolled accommodation, and night myopia, and the determination of a specific diopter refractive error with the system, for the purpose of fitting corrective lenses, is not feasible; however, the system is capable, through careful image analysis, of projecting a probability that 53 percent of refractive error indications in subjects with 8 to 9 mm pupils, greater than minor or fringe, that the refractive error would exceed one diopter. The probability increases to 82 percent and 85 percent for 7 mm and 5 to 6 mm pupils. In most cases, clinicians do not prescribe corrective lenses for refractive errors of less than one diopter.

Photorefraction of subjects wearing corrective lenses presented a special problem in that, in many subjects, the photorefractor electronic flash would reflect off the subject's glasses and partially obscure the retinal reflex image. Fifteen percent (103) of all subjects photorefracted had corrective lenses, only two having contact lenses which did not present any problem. All subjects wearing glasses were photorefracted with and without their glasses, and 42 percent indicated a flash reflection off of their glasses. Only two subjects had flash reflections that totally obscured the retinal reflex image. Eighty-one percent of the subjects indicated refractive error without their lenses, and nine percent indicated refractive error while wearing their lenses. Of the twenty subjects that were photorefracted without their lenses and did not indicate any refractive error, thirteen had pupil sizes ≤ 6 mm and if they had refractive errors of <1.00-1.25D, it would not have been indicated. The remaining seven had 7-8 mm pupils and under normal conditions, refractive error should have been detected unless they were accommodating or astigmatismic.

B. Summary

1. System screening capabilities

- Detection of refractive errors 1.00 to 1.25D with 5 to 7 mm diameter pupils
- Detection of refractive errors 0.25 to 0.5D with 8 to 10 mm diameter pupils
- Detection fo 0.25 to 0.50D difference in anisometropia

- Detection of small angles of strabismus
- Detection of small lens obstructions >1 mm
- Determining the ocular status of very young, noncommunicative children
- Determining the contact lens power in infants
- Determining the ocular status of all school age children and young adults

2. System and procedure limitations

- Difficulty in determining small to moderate refractive error in the range <1.00 to 1.25D in subjects with pupil sizes ≤5 mm in diameter
- The specific refractive error values cannot be determined
- Refractive error indications can be affected by accommodation, astigmatism and, in some subjects, night myopia
- Retinal reflex images can be partially obscured or degraded by ptosis, flash reflection off corrective lenses, and subject blinking at the time of photorefraction

C. Recommendations

1. Photorefraction of subjects with glasses

It is recommended that a technique be developed to eliminate the electronic flash reflection that appears on the glasses of subjects being photorefracted, possibly experimenting with polarizing filters for the flash or camera lens.

2. Reduction of night myopia

It is recommended that tests be conducted to determine the optimum light levels for photorefraction in a darkened environment. In addition, consider replacing the red flashing light focusing aid with a single digit numeric LED display that would provide a sharper image for the eyes to focus on in the darkened environment.

3. Improved Detection of Astigmatism

The 2.4-m PR with the electronic flash mounted below the camera lens detects refractive error for the vertical meridian of the eye only and the axis of astigmatism is not determinable, especially for oblique and horizontal axis. Since 37 out of the 60 subjects examined by the ophthalmologist had astigmatism, it may be beneficial to modify the system to increase its capabilities to detect astigmatism. Anthony N. Norcia, PhD, research at Smith-Kettlewell Eye Research Foundation, who evaluated our earlier prototype 4.2-m system, suggested that a second electronic flash be incorporated into the system and mounted on the horizontal axis relative to the camera lens. This would require taking two pictures of each subject, and to reduce the possibility of pupil constriction following the first flash, it would be necessary to take the second picture within 2 sec which would require the addition of a motor drive to the camera and a unique flash switching circuit. The suggestion has merit and should be evaluated for the enhancement of future photorefractor systems to improve the detection of astigmatism.

REFERENCES

1. Norcie, Anthony M., and Zadnick, Karla: O. D. Evaluation of the GRRIS Off-Axis Photorefractor. Smith-Kettlewell Eye Research Foundation.

2. Leibowitz, H. W., and Owens, D. A.: Night Myopia and the Intermediate Dark Focus of Accommodation. The Pennsylvania State University, Department of Psychology. Journal of the Optical Society of America, Volume 65, No. 16, October 1975.

3. Kaakinen, Kari: A Simple Method for Screening of Children with Strabismus, Anisometropic or Ametropia by Simultaneous Photograph of the Corneal and Fundus Reflexes. Department of Ophthalmology, University of Helsinki, ACTA Ophthalmologica, Volume 57, 1979.

4. Dorland's Medical Dictionary, Twenty-Fifth Edition, 1974.

APPROVAL

TEST AND EVALUATION OF THE 2.4-m PHOTOREFRACTOR OCULAR SCREENING SYSTEM

By John R. Richardson

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

Director, Technology Utilization Office