FOREWORD

This report was initiated by the Vision Section, Protection Branch, Life Support Systems Laboratory, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. This report is based on the research and development work by the Division of Optometry of Indiana University, Bloomington, Indiana, under Contract No. AF 33(616)-6146, Project No. 7163, "Physiology Research," Task No. 716303, "Physiology of the Visual Mechanism." The author, Professor Merrill J. Allen of the Division of Optometry, is the Principal Investigator. This report covers the period from 1 May 1961 to 31 March 1962. Donald G. Pitts, Captain, USAF, MSC, served as Contract Monitor for the Vision Section.

ABSTRACT

An infrared optometer for measuring the absolute status of accommodation is subject to a constant error not associated with chromatic aberration or changes in fixation. The reflections of infrared light within the eye cannot be considered to originate from the retina or pigment epithelium alone. Probably the choroid and sclera are involved giving a diffuse reflection and increased intraocular stray light. A schematic eye, using a retina of 2-mm. opalescent plexiglas with a sanded surface, approximately simulates the behavior of the human eye. Changes in fixation have only a slight effect on optometer accuracy as long as the pupil does not vignette the optometer beam.

A modification is described for calibrating the infrared optometer for an individual subject without using trial lenses or a subjective optometer.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

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CALIBRATION OF THE INFRARED OPTOMETER

INTRODUCTION

The apparatus used in this study is described in detail in ASD Technical Report 61-111.* The infrared optometer portion of the apparatus has shown great promise as a new research tool for studies on the motor aspects of vision. As a new tool, however, its characteristics have had to be put under careful study to ensure that the data it provides are meaningful.

When this instrument was put into routine use it was not realized that it would behave differently on the human eye than on the schematic eye used for its early calibration. It soon became apparent that the data obtained differed from those anticipated. Various factors were studied such as the stimulus situation employed, the subject's ability to cooperate, the subject's training, his eye position alignment, the reflectivity of the vitreous retinal boundary, technical difficulties in dry ice or electronics, and/or the training of those responsible for data taking.

With the delay in recognizing that a human calibration problem existed with infrared, and with the multiplicity of factors that could cause the problem, each of which had to be checked out in detail, it became necessary to request a contract extension. The problems have become resolved into the scattering of infrared light and the need for better training of subjects. This report will cover the method by which the instrument has been brought into meaningful calibration.

INFRARED APPARATUS, BRIEF DESCRIPTION

Figure 1 is a schematic of the optics of the infrared optometer and haploscope. The infrared optometer is directed into the right eye and operates as follows. The source S is imaged at S' by lens L_4. After refraction at L_2 and by the optics of the eye, it is imaged on the retina at S". The returning rays from S" are imaged again approximately at S' before striking mirror M_4 and being focused by L_5 at the analysing aperture A". Those rays which pass through A" are detected by the photomultiplier tube.

When the subject accommodates, S" moves downward on the retina, because the rays enter the eye through the upper portion of the pupil at A'. A' is the image of A. Light from S passes beneath the mirror M_4 through the lower aperture of A. Only the returning light that passes through the upper aperture of A is reflected by M_4 to the photomultiplier tube. Downward movement on the retina appears at A" as a movement toward the left. The aperture in A" is adjusted so that lateral movements of the light image cause more or less light to be lost on its way to the photomultiplier tube, thus providing a means for measuring accommodation.

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* Allen, M. J., <u>A Study Concerning the Accommodation and Convergence Relationship</u>, ASD TR 61-111, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, May 1961.

Lenses L_1 and L_3 serve to image the visible targets illuminated by B_1 and B_2 at appropriate levels of stimulus to accommodation. M_3 is a special dichroic mirror reflecting almost all visible light and transmitting almost all infrared light at 850 mu wavelength. F is an infrared filter.

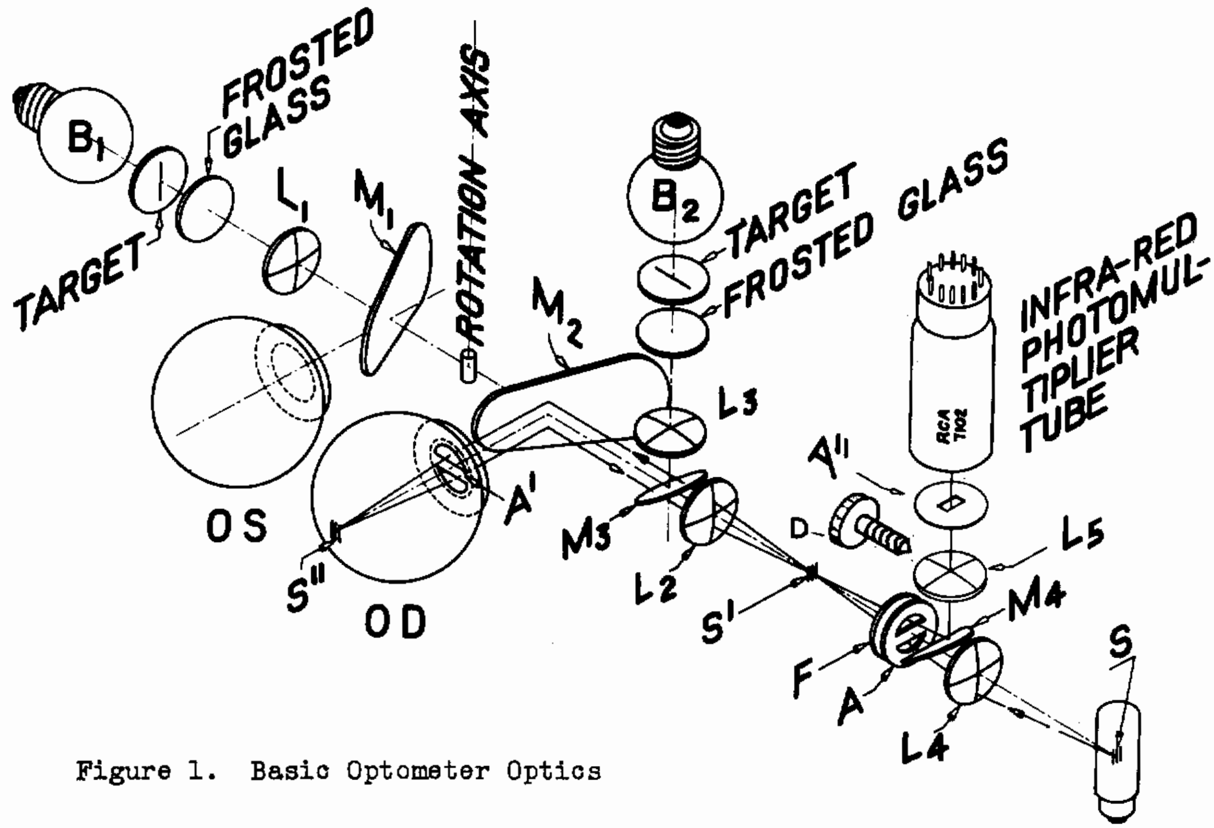

Figure 1. Basic Optometer Optics

MODIFICATION OF THE INFRARED OPTOMETER
TO SIMULATE ACCOMMODATION

The infrared optometer optics were modified slightly to make adjustable the image of S" which falls in the plane of aperture A". Movement of this image would then simulate movements induced by accommodation. A movement of approximately 0.150 mm. at A is equal to 1 diopter change in ocular focus. Such a small movement was satisfactorily obtained by moving lens L_5 to the left (from the subject's point of view) by means of a screw adjustment acting against the lens housing. Figure 2 shows the external arrangement of the photomultiplier support structure containing the fixed aperture A" and the movable lens L_5. Lens L_5 was attached to C by an arm extending through the wall of the large vertical tube. C was set screwed onto a shaft supported by the bearing B.

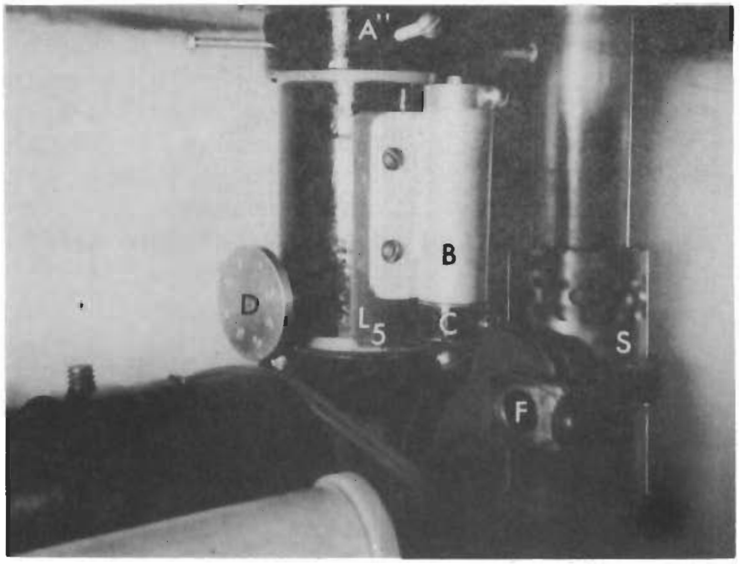

Figure 2. Lens Positioning Mechanism

Due to the small movement needed, the lens can be assumed to travel a straight line, though it moves on the arc of a circle. Within the housing a leaf spring presses on one side of the L_5 lens housing to hold it against the adjusting screw. This provides essentially no load on the bearing and back lash appears to have been completely eliminated. Movement of the lens was chosen rather than moving the aperture A" because A" is partially buried within the insulated dry ice container housing the phototube. Even though movement of the lens is about one-half the movement that A" would have to undergo for the same effect, a satisfactorily fine adjustment has been provided.

CALIBRATION PROCEDURES

Electronic

The infrared photomultiplier tube measures the amount of light returned from the eye past aperture A". Since there is an appreciable dark current associated with the entire electronic system, the filter slide, F, see figure 2, can be shifted to cut off the infrared light and a "zero" balancing potentiometer is provided to balance out the dark current. With the calibration dial, D, set at zero, and with the subject fixating a specific accommodative stimulus at his zero level of accommodation, infrared is readmitted to the system and the output of the amplified signal from the photomultiplier is noted on a microammeter. The brightness of S is adjusted by varying the voltage applied to it until a predetermined output is achieved--usually 50 microamperes.

Schematic Eye

To determine the number of microamperes per diopter of accommodative response, a Fischer schematic eye was used instead of the human eye and plus spherical trial lenses were placed immediately in front of it to simulate accommodation. The retina used was white nonglossy paper which provided a reasonably sharp border when a spot of light was focused upon it. In addition, a 2-mm.-thick sheet of white opalescent plexiglas could be placed in front of and in contact with the paper retina. When using the plexiglas retina the schematic eye was lengthened by 2 mm. to allow for its thickness. The exposed surface of the plexiglas was sanded to eliminate specular reflections, and an image of a point focused on it was considerably softened by the diffusion in the plastic. Calibration curves were also obtained using the calibration dial, D, instead of trial lenses, with the schematic eye set at emmetropia.

Human Eye

The right eye of the test subject was used for infrared optometer measurements. Paredrine hydrobromide, 1 per cent ophthalmic solution, was used for mydriasis during all infrared optometer measurements. During calibration runs with trial lenses, Cyclogel 1/2 per cent ophthalmic solution was used to prevent accommodative changes when the fixation target became excessively blurred with the plus trial lenses. The subject was required to fixate the center of the visible target and to hold his head still by means of a firm grip with his teeth on the bite board provided. Periodic checks on head alignment were made because the subject tends to relax his bite permitting his head to shift as he fatigues. Only a small amount of head movement and eye fixation change is permissible as long as the margin of the iris does not vignette either the entering or exiting beam.

Data were also obtained with mydriasis but without cycloplegia so that the subject could accommodate on letters set at various stimulii to accommodation. Due to the dilated pupil and the special training of these subjects it was felt that the accommodation accurately followed the stimulus.

CALIBRATION RESULTS

Schematic Eye

Figure 3 shows the calibration curves obtained with the schematic eye equipped with a paper retina. The aperture displacement curve is displaced from the trial lens curve due to an error in spacing of the diopter markings on the calibration dial. No allowance is made in the schematic eye curve for the fact that the trial lenses are about 2 mm. from the principal planes of the schematic eye.

The trial lens curve is essentially the same curve as presented in ASD Technical Report 61-111. Since this curve does not agree with the curves obtained on humans (see figures 6, 7, and 8), it was decided to test the theory that the human eye is different from the schematic eye because it has more stray light at these wavelengths. A 2-mm.-thick piece of white plexiglas having very good light-scattering properties was used for the retina in the schematic eye.

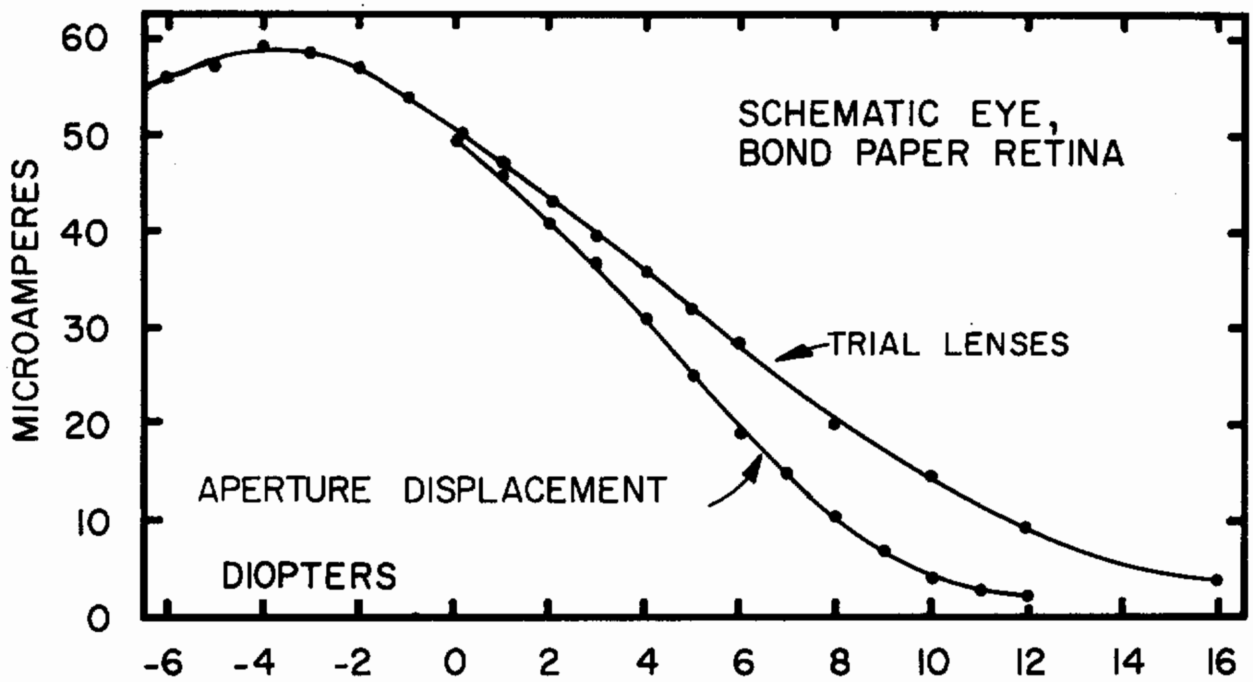

Figure 3. Calibration Data, Schematic Eye with Paper Retina

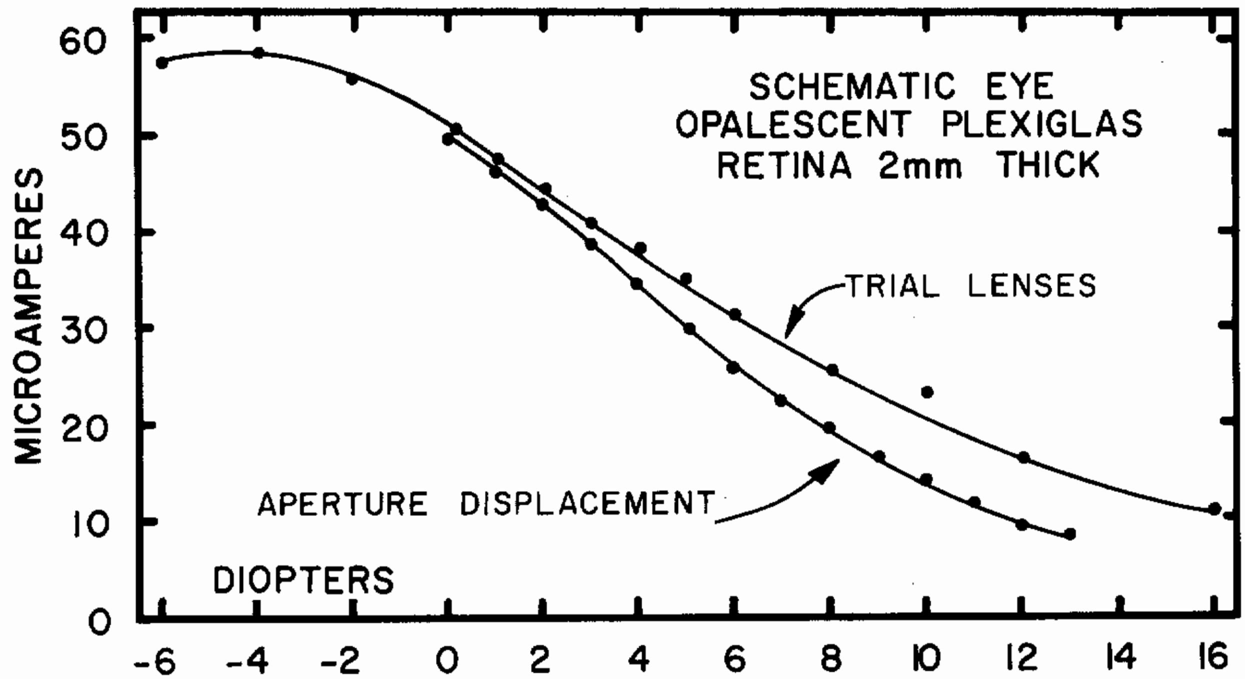

Figure 4. Calibration Data, Schematic Eye with Plastic Retina

Figure 4 shows the results when the schematic eye with a diffusing retina was used. The curves show remarkable agreement with those of figures 6, 7 and 8 taken on humans and suggest that the real retina and pigment epithelium are easily penetrated by infrared radiation which is diffused by the choroid and sclera to provide a "soft" image in depth.

Human Subjects

It is difficult and time consuming to take a calibration curve on every human subject. Because the control of accommodation is apparently not easy for some people, personal calibration curves may not be accurate. It was hoped that some method of simulated accommodation could be provided that would be simple and accurate. The data presented in figures 6, 7, and 8 suggests that aperture displacement by means of the calibrated dial is a suitable method.

Figure 5 is a comparison of the power of the trial lenses with their effective power at the principal planes of the eye assuming both a 10-mm. and a 16-mm. vertex distance (8 and 14 mm. from cornea). There is little reason to consider the curves in figures 6, 7, and 8 beyond 10 diopters which is equal to about 12 diopters in the spectacle plane. Furthermore, since the vertex distance, tilt of the hand-held lenses, etc., could not be carefully controlled, the lens calibration data is subject to some question, though it is very similar to the subject's accommodative response to a specific stimulus.

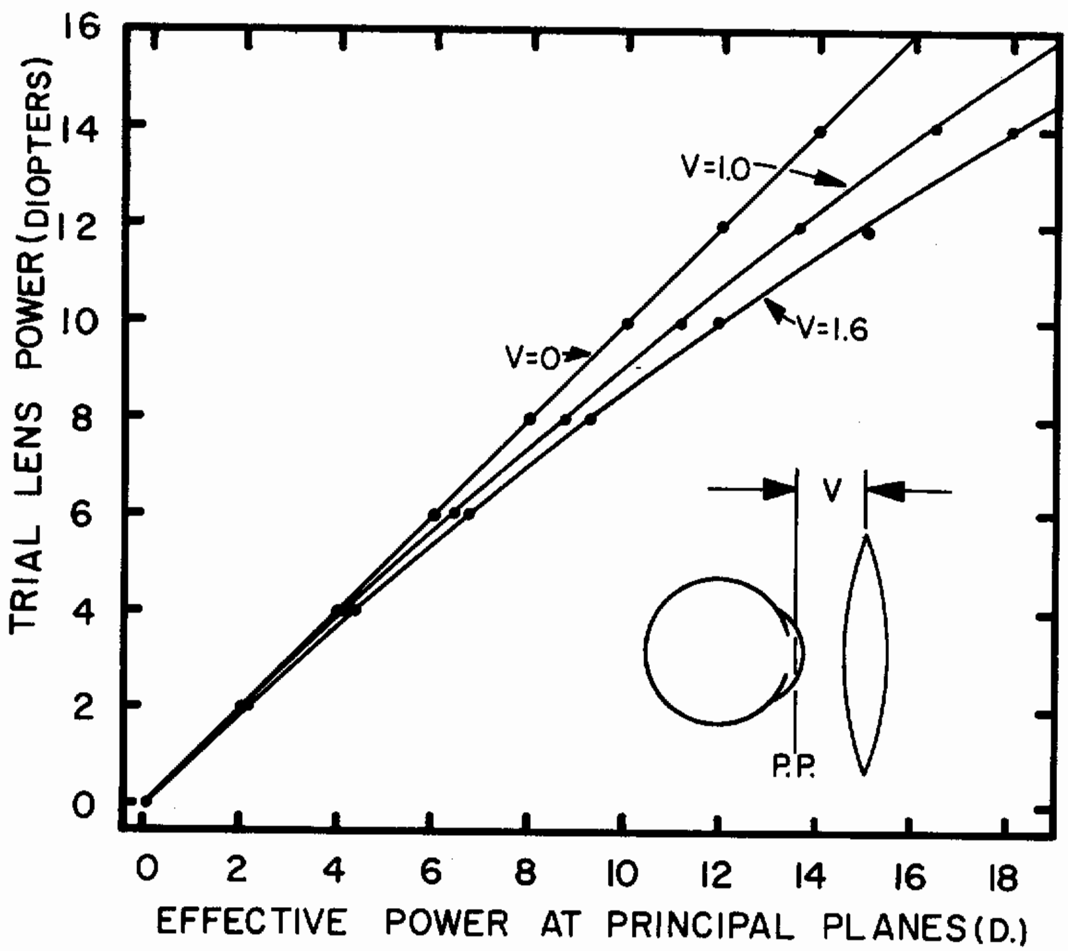

Figure 5. The Effective Power of Trial Lenses at the Principal Planes of the Eye

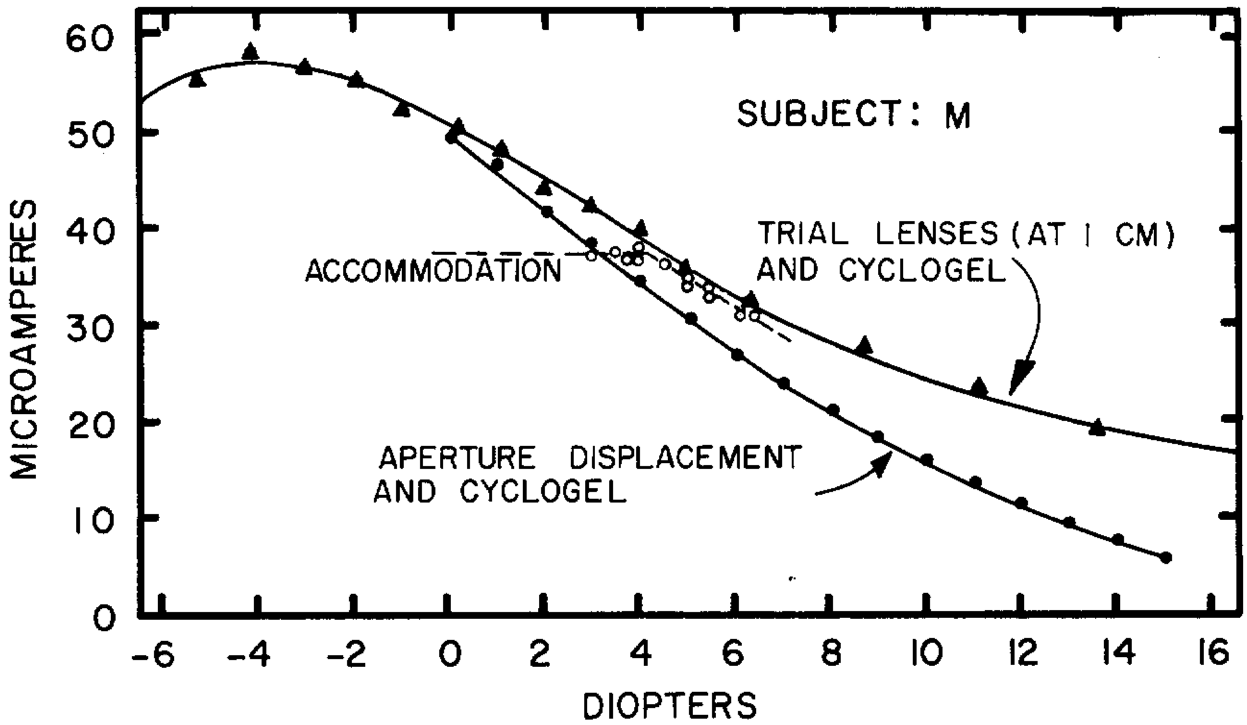

Figure 6. Calibration Data for Subject M

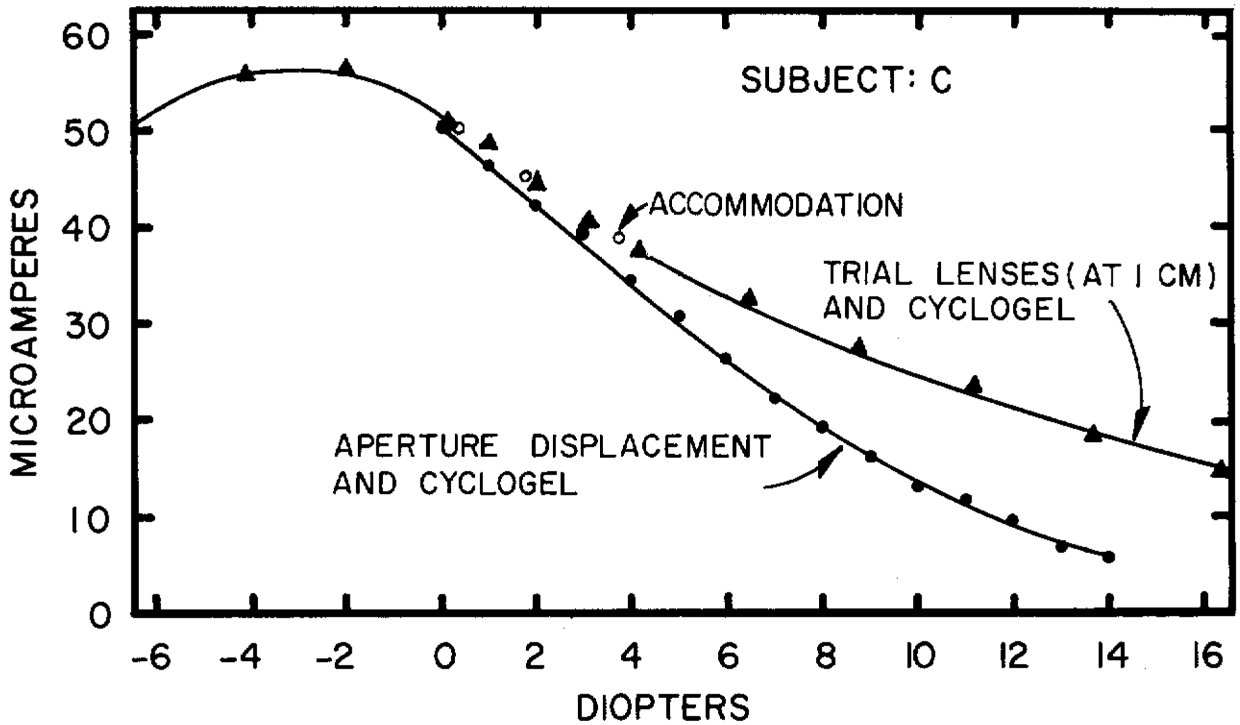

Figure 7. Calibration Data for Subject C

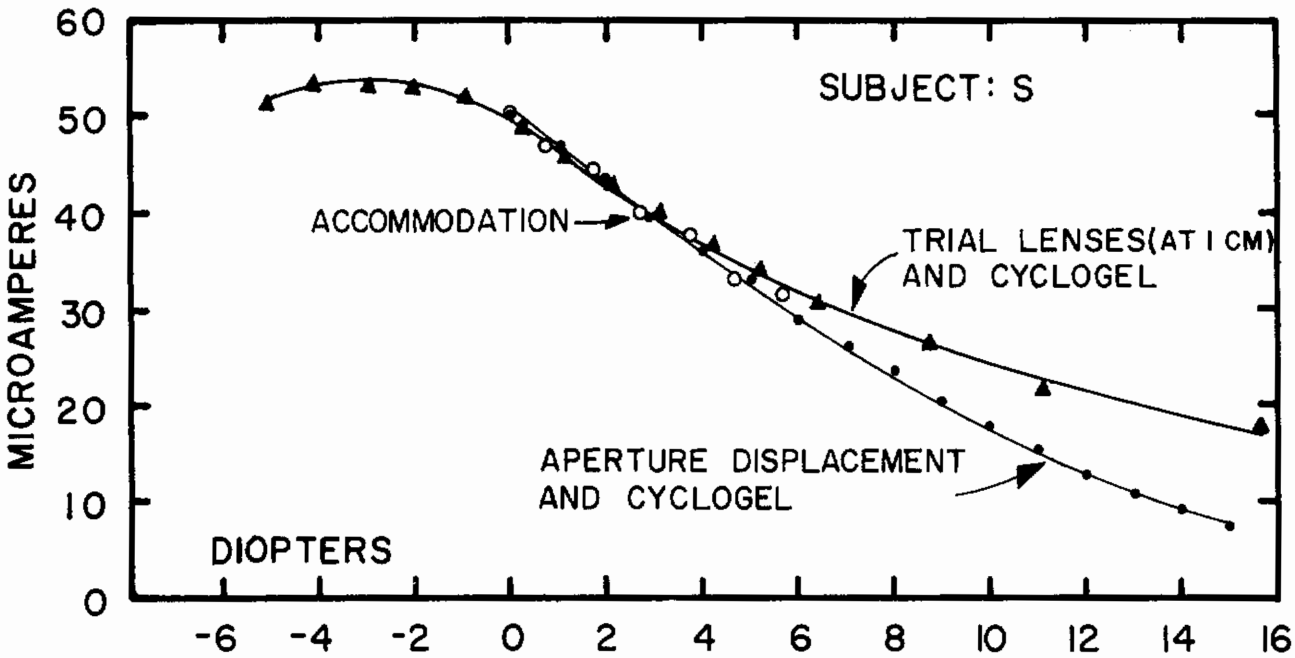

Figure 8. Calibration Curve for Subject S

DISCUSSION

Direction of Fixation Effect

Changes in fixation might produce changes in photomultiplier output without any real changes in accommodation. Variations in retinal elevation, fundus reflectivity, obliquity through the optical system, and optical irregularities from one area of the pupil to another, as well as the possibility of pupil interference with the optometer beam, could cause the infrared optometer to indicate an accommodative change when none has occurred.

To determine the extent of fixation interference in accommodation recording, each subject was requested to fixate various points in the field of view while optometer readings were made. The results are given in tables I, II, and III as the micro-ampere output of the photomultiplier-amplifier circuits. The dioptric equivalents would be obtained by referring to figures 6, 7, and 8.

Enough points are present to show approximately the maximum variation that would occur on fixating the limits of the field and to show that changes in fixation about the center of the field will cause small but predictable changes in optometer output.

Table I FIXATION EFFECTS, SUBJECT C

		FIXATION LEFT			FIXATION RIGHT	
	DEGREES	6.85°	0.85°	0°	0.85°	6.85°
FIXATION UP	6.85°			42.5μa		
FIXATION UP	2.85°			46μa		
	0°	53μa	50.8μa	50μa	49.2μa	50μa
FIXATION DOWN	1.26°			50μa		
FIXATION DOWN	6.85°			57μa		

Table II FIXATION EFFECTS, SUBJECT M

		FIXATION LEFT			FIXATION RIGHT	
	DEGREES	6.85°	0.85°	0°	0.85°	6.85°
FIXATION UP	6.85°			49.0μa		
FIXATION UP	2.85°			49.3μa		
	0°	53.5μa	49μa	50μa	49.8μa	53μa
FIXATION DOWN	1.26°			51.5μa		
FIXATION DOWN	6.85°			49.7μa		

Table III FIXATION EFFECTS, SUBJECT S

		FIXATION LEFT			FIXATION RIGHT	
	DEGREES	6.85°	0.85°	0°	0.85°	6.85°
FIXATION UP	6.85°			42μa		
FIXATION UP	2.85°			46μa		
	0°	53.5μa	49μa	50μa	50.5μa	59μa
FIXATION DOWN	1.26°			48.5μa		
FIXATION DOWN	6.85°			50μa		

Corneal Drying and Subject Fatigue

During the experimentation it was observed that the subject sometimes stared unblinkingly for long intervals. When the cornea showed positive evidence of drying a spurious optometer reading would be obtained which would be corrected as soon as the subject blinked. Subjects wearing contact lenses that were oily or dirty showed very erratic optometer performance, both due to dryness and to prismatic effects as the lens shifted.

With fatique, the rate of blinking sometimes became excessive and interfered with data taking. With extreme fatigue the subject was unable to maintain a good stable head position even with the dental bite presumed to be firmly between his teeth. When the data obtained became erratic, the cause would be quite apparent when the special aligning lights were turned on and improper eye position was indicated. Sometimes it was sufficient to call the subject's attention to the problem to maintain better head and eye positioning. Frequently, however, further experimentation was useless without a suitable period of rest. Therefore, care must be exercised in interpreting small changes in the accommodation record since they might be caused by factors other than accommodation. Most such factors would create their effects at random.

The high reflection of infrared within the eye and within and behind the retina offers an attractive explanation of why the schematic eye data does not agree with the human eye data. The remarkable agreement when a diffusing retina was introduced is most suggestive. The calibration curve obtained by displacing the aperture cannot be considered valid beyond 10 diopters because blur normally increases in this optometer system beyond this limit and a blur increase is not simulated by movement of the aperture. Should the subject be ametropic more than about ± 1 diopter, the calibration by aperture displacement must be corrected slightly.

The movement of the aperture by means of the calibrated disc is quite simple and quickly gives a calibration curve for a given subject. Even without automatic recording a curve, like those in figures 6, 7, and 8, can be obtained in about two minutes including the initial adjustment of the optometer electronics.

SUMMARY AND CONCLUSIONS

A method of calibrating the infrared optometer output against the dioptric changes of the schematic and human eyes has been presented. Corrections to schematic eye data to make it agree with human eye data suggests that the infrared light probably undergoes scattering within the retina choroid and sclera of the human eye, thus effectively reducing the sharpness of imagery on the retina for wavelengths near 850 millimicrons. Small changes in fixation have little effect upon the output of the optometer. Fatigue may cause head movements which spoil the alignment of the beam of light entering the subject's pupil. Sometimes insufficient blinking causes corneal drying and irregular optometer performance.

In general, the internal calibration of the optometer for a given subject is practical and fast, and it yields results comparable, if not superior, to trial lens simulated accommodation. Correction of the dial scale is indicated.