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ACCOMMODATIVE POSTURE AT ZERO FIELD LUMINANCE LEVELS

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Abstract

The reaction of the accommodative mechanism to a zero level of field luminance was studied. Accommodative posture was measured by photographing the third Purkinje image in darkness, and in light with the subject fixating on and maintaining subjective clarity for a distant target. Comparison of the two series of photographs revealed fluctuating positive accomodative action in the dark with individual increases to 2.00 diopters. Mean accommodative level for 14 subjects was 0.94 diopter.

Introduction

For many years, discussions have existed in the literature concerning the posture of accommodation in the absence of visual stimulus and the possibility of a resting level of accomodation about a point other than its infinity position. Many investigators have studied the commonly observed refractive changes that accompany low levels of illumination, the so called night myopia, and their investigations have generated a number of possible causes for the apparent increase in refractive power of the eye under these conditions. Only a few studies, however, have been performed to determine objectively the behavior of accommodation in the complete absence of visual stimulus and these, possibly because of their varied experimental means, offer wide, and in some instances conflicting, results.

The purpose of the present investigation was to objectively study observed accommodative changes in a totally dark environment, uninfluenced by any distracting or otherwise contaminating element that may have raised questions about some of the earlier works.

Background

Early studies of accommodative behavior in the dark have been largely limited to subjective determinations of total refractive change in dim illumination. Until the 1950's, efforts of investigators were hampered by lack of accurate objective means of observing the refractive changes that would not, at the same time, contaminate their findings by providing excessively bright stimuli to accommodation. Since that time, several investigations have been made using either high speed photography or infra-red skiascopy to record the activity of accommodation in the absence of visual stimulus.

Objetive experiments performed by Otero[4] in 1950 were among the first to indicate accommodative ac [illegible]
mophakometer he photographed the third Purkinje images in darkness, and in light with the eye accommodated for various distances corresponding to known dioptric stimuli. By these means he determined the natural resting level of accommodation corresponded not to zero diopters, as had formerly been thought, but to a positive accommodative level of 1.25 diopters.

In 1953 Koomen[3], et al, performed similar ophthalmophakometric studies of accommodative posture in the dark in which he found no positive accommodative activity in a dark environment for 3 subjects of a 4 subject group. The one outstanding individual exhibited positive accommodative activity of an erratic and unpredictable degree. Koomen's experimental procedure differed from Otero's, however, in that he used a fixation light, periodically flashed, to properly orient his subject's gaze in the dark.

Also in 1953 Campbell[1] conducted Purkinje image studies of accommodative activity in the dark. Campbell's studies also utilized a small fixation light for subject orientation, which disappeared when coincident with the dark adapted fovea, thus indicating when the visual axis of the subject was properly aligned. Campbell's results indicated a continual fluctuation of accommodation in the dark between absolute levels of 0.25 and 1.20 diopters.

Following these earlier experiments, Heath[2] performer Purkinje image and infra-red retinoscopic studies of accommodation in absence of visual stimulus. His findings indicated a rapid increase in positive accommodation to about 2.0

diopters obtains when the eye is first confronted by a totally dark environment. This, according to Heath, is followed by a continual fluctuation thereafter, between the limits of 0.62 and 1.25 diopters.

Instrumentation and subjects

The method used to objectively study accommodative behavior in this investigation was that of analysis of the size changes of third Purkinje image photographed in darkness, and in light with the subject fixating and accommodating at infinity.

The equipment followed the general plan of that used by Otero and Campbell. The third Purkinje image is the catoptric image of an external light source reflected from the convex anterior surface of the crystalling lens. Authorities generally agree that the anterior lens surface becomes more convex in shape during the active accommodative process, and it is expected, therefore, to find that the third Purkinje image decreases in size during accommodation.

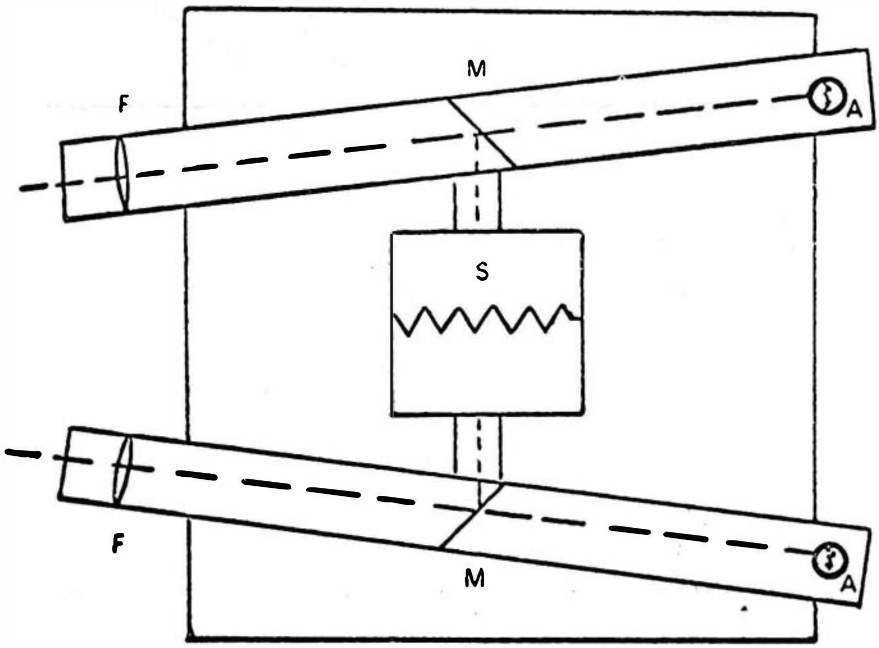
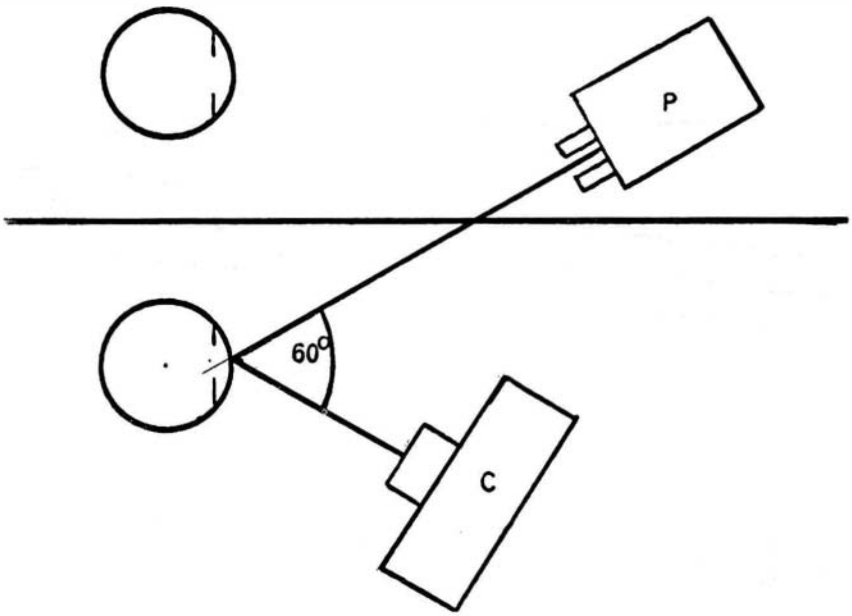


Figure 1. Schematic of Ophthalmophakometer Used for Objective Studies of Accommodation in Total Darkness.

The Photographic apparatus used in this experiment is shown in Figure 1. An electronic flash unit S, of 1200 candle-seconds energy output and flash duration of 0.001 second, was mounted in a light tight metal box. Two metal tubes which opened into each side of the flash unit converged toward the front of the housing. Partly silvered mirrors M (transmittance 40%, reflectance 60%) were placed within the tubes so that some of the light generated by the electronic flash unit was reflected toward the ends of the tubes nearest the subject. Behind the mirrors, at the distal ends of the tubes, were mounted a pair of auto headlight bulbs of 21 candles intensity each, which were used during focusing of the camera to be described.

The entire unit was positioned 40 centimeters from the subject's eye at an angle of 30 degrees nasal to the line of sight. See Figure 2.



c :camera
p : phakometer

Figure 2. Details of the Arrangement of the Ophthalmophakometer-Camera Apparatus Used in Objective Measures of Accommodation.

A Pentax single lens reflex 35mm camera, having a 55mm, f/1.4 lens, was mounted at an angle of 30 degrees temporal to the line of sight. Auxiliary tubes were used to extend the camera lens for proper focusing at 7 centimeters from the subject a distance that created a one-to-one object-image ratio. This would

have allo [illegible]
factor necessary to find the actual Purkinje image size, is such were desired.

During preliminary focusing and positioning of the apparatus the lights, A, at the distal ends of the flash tubes (Figure 1) were turned on, providing constant Purkinje images for focusing of the camera. When photographs were made, the focusing lights were extinguished. Upon release of the camera shutter, light from the flash unit, S, traveled the tubes, was collimated by lenses F at the exit ports of the tubes, and proceeded to be imaged catoptrically as two dots by the anterior face of the crystalline lens after refraction at the other ocular surfaces. Purkinje images one and four, reflected from the anterior corneal surface and the posterior surface of the crystalline lens respectively, also appeared with the third image but were not used.

Film used was Kodak Tri X, 35mm. Exposure time was 1/50 of a second at f/5.6. The film was developed for maximum contrast. All measurement of third Purkinje image size were made directly from the negatives by means of a measuring microscope.

Fourteen subjects, thirteen males and one female, participated in the experimental procedures. Subjects ranged in age between 20 and 30 years, with the exception of two whose ages were 40 and 41. Selection of subjects was made on a three point basis: 1) refractive error. 2) quality of the third Purkinje image, and 3) pupil size.

1. *Refractive Error*

All subjects selected were nearly emmetropic in each eye, only one being more than plus or minus 0.25 diopter from a plano refractive state in one meridian as determined by normal refraction techniques. The one exception to this was subject NL, whose static refraction was 0.75 diopter of myopia.

A slight amount of astigmatism, up to 50 diopter ,was allowed. This condition of subject selection was maintained in an attempt to keep the procedures uncomplicated by some optical or visual factor that might have led to spurious results.

2. *Quality of Third Purkinje Image*

Considerable difficulty was encountered in selecting eyes with lens surfaces that would provide suitable images for Purkinje image photography. The irregularity of third images among individuals has been described in the literature.

being attributed in part to changes with age (Wulfeck [6]). However, Heath [2] found similar conditions in his studies of high school students 15 to 18 years of age.

A wide range of image quality was noticed by this investigator during the process of selecting subjects for the experiments being described. Twenty-five subjects were examined in order to obtain fourteen with the necessary lens quality for the experimental work.

3. *Pupil Size*

Only those individuals who exhibited 4mm or larger diameter pupil sizes in daylight illumination were accepted as subjects. Persons having pupil sizes smaller than 4 mm in diameter were rejected. This restriction was necessary to ensure pupillary apertures large enough to permit Purkinje image photographs to be taken easily in the normal room illumination for calibration purposes.

Procedures

Three groups of photographs were taken of each subject. The first, using moderate room illumination with subject maintaining subjective clearness for a distant target, was taken to establish a base, or infinity dimension for the individual Purkinje image to which all other measurements could be compared.

The second group consisted of calibration photographs, used to determine the Purkinje image size for each stimulus to accommodation. Methods of calibration by accommodative stimulus, rather than accommodative response, were used to permit accurate comparison of these data to those of earlier experimenters, all of whom also used stimulus calibration methods.

The third group of photographs was taken of the Purkinje images in total darkness using the procedures described below. Dimensions of these images were subsequently compared to those in group one to determine the amount of accommodation, if any, that had occured in the dark.

A. *Purkinje Image Photography, Moderate Room Illumination.*

The subject's chin was placed securely in the chin rest provided and his attention was directed to the illuminated Snellen target, 7.6 meters distant. Target luminance was approximately 8 foot-lamberts. Focusing lights of the instrument were switched on. The camera was positioned and focused on the third Purkinje image which appeared centered in the subject's pupil when his eye was properly aligned. The subject was requested to keep the target as clear as possible. Focusing lights were switched off and the camera shutter was tripped, automatically triggering the electronic flash unit.

B. *Calibration Photography, Moderate Illumination.*

The process in (A) was repeated, with subject fixation on the target now placed in succession at 6 meters, 2 meters, 1 meter, and 0.5 meter from the eye, again using target luminance of 8 foot-lamberts. These were calibration photographs to determine the Purkinje image size for each stimulus to accommodation.

C. *Purkinje Image Photography, Total Darkness.*

All lights were extinguished and a photograph was taken immediately. Estimated time in the dark before this first photo was 30 seconds for most individuals. The subject was allowed to adapt to the dark for 5 minutes. Another Purkinje image photograph was taken then and after each 5-minute interval for a total period of 20 minutes. A total of 5 photograps was taken in the dark for each subject.

The procedure was essentially the same as outlined in (A) above, but with some necessary modifications. The correct position of the subject's eye had been established in taking the previous photographs. In total darkness, the subject was requested to fixate on the spot where the target had formerly appeared. To reinforce his orientation a weak light was flashed at the desired fixation stop 10 seconds before the photograph was to be taken. A 0.02 second flash duration was used to avoid creating any change in accommodative posture. The subject was asked to look toward the spot where the test light flashed, and the camera shutter was tripped.

Early in the investigation considerable difficulty was encountered in establishing the precise fixation necessary for accurate photography of the Purkinje image in the dark. Needless to say, even slight inaccuracies of fixation were sufficient to render the photographs completely useless. Numerous procedures were tried in an attempt to gain accurate fixation in the dark. Included in the attempts were:

1. Subject directed to point with arm and forefinger toward the imagined spot of fixation in an attempt to direct the eyes to the proper place.

2. Subject required to hold taut one end of a string extending from the desired fixation spot to the subject.

3. Placement of a sound generator at the desired fixation spot in an effort to guide the direction of gaze by the direction of the emitted sound.

4. Brief flash of light at the desired fixation spot just prior to taking the photograph. The flash was of a duration shorter than the reaction time of accommodation and therefore was not expected to influence the existing accommodative posture of the subject.

Techniques (1), (2) and (3), above, were tried and abandoned as unsuccessful. Ultimately, technique (4) was employed as the most fruitful approach.

Supplemental Test: Extended Period in the Dark.

One subject was selected to undergo further testing, which consisted of Purkinje image photography in total darkness over a period of one and one-half hours. Photographs were taken at three minute intervals. The subjetc was seated before the instrument as described earlier. Lights were then extinguished, and subsequent photos were taken at three-minute intervals. The subject directed her fixation toward the last seen position of the fixation target, but no reminder lights or other fixation aids were used in this portion of the experiment.

Results

Representative photographs of third Purkinje images as obtained in this investigation are shown in Figures 3, a, b, and c. The two bright images seen in the extreme right portion of the pupil are Purkinje images number one, the corneal images. Those in the extreme left portion of the pupil are Purkinje images number four, reflected from the posterior lens surface. Purkinje images number thee are seen centrally in the pupil and are less bright than the adjacent corneal images.

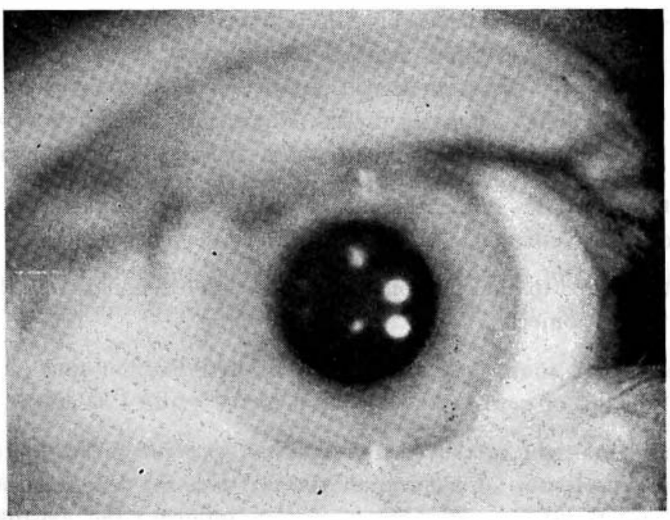


Figure 3a. Normal Room Illumination.

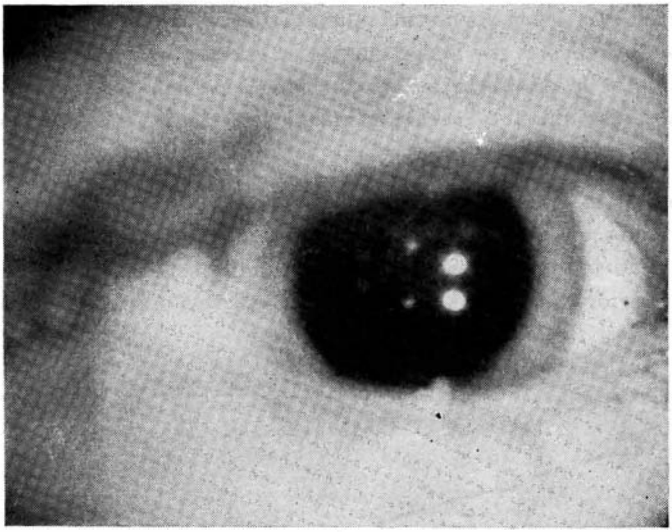


Figure 3c. Ten Minutes in the Dark.

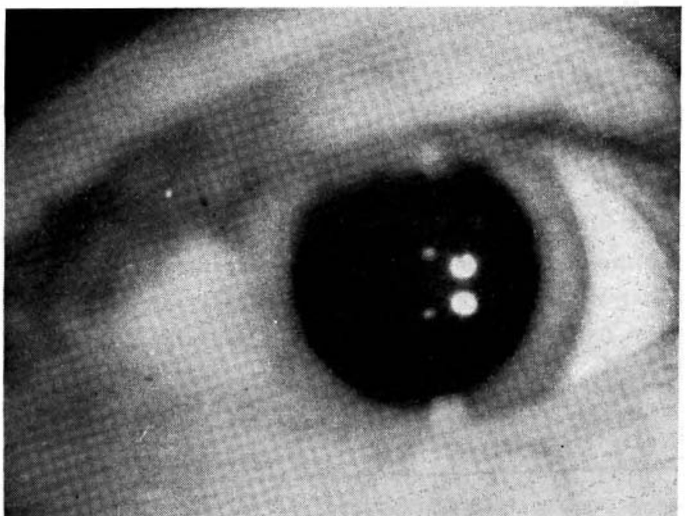


Figure 3b. Five Minutes in the Dark.

Figures 3a, 3b, and 3c: Sample photographs of third Purkinje images obtained in this investigation. Subject WL. Note the large pupils in the dark in b and c.

Photograph 3a was taken in normal illumination with subject fixation at 7.6 meters. Figure 3b indicates the image change at the end of a five-minute interval in the dark; Figure 3c shows the results of a longer period (ten minutes) of dark adaptation. Close examination reveals an image size change between photographs 3a and 3c.

Measurement of the image size made directly from the negative by means of a measuring microscope. Comparison of the third image size on the photographic negatives made during experimental darkness conditions with the image size on negatives made prior to the dark, when the subject was fixating known distance

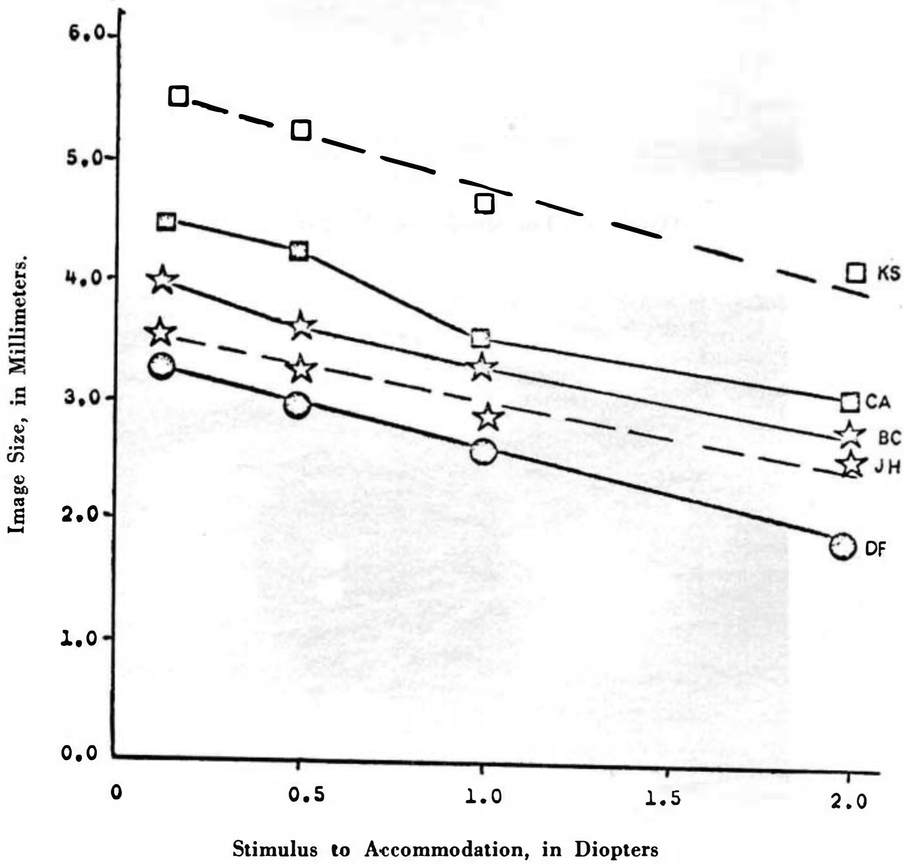


Figure 4. Sample Calibration Curves for 5 Subjects Showing Variation in Third Purkinje Image Size as a Function of Dioptric Accommodative Stimulus. Each plotted point represents one measurement. Dashed lines are estimates of the line of best fit in each case.

in normal illumination, permitted an estimation of the diopthic amount of accommodation that occurred during the absence of visual stimuli. Sample calibration curves drawn from these data are shown in Figure 4.

As will be noted in Figure 4, the slopes of the straight lines relating image size to accommodative stimuli (as measured by Purkinje image photography in the calibration procedures) are not necessarily the same for all individuals tested. The variation is small, however, and for purposes of enumeration in this experiment a fixed ratio of 0.25 diopter of accommodation change per 0.2 mm image size change is used, except for subjects CA, DS, BC, and JP where values derived from individual calibration curves are used in the interest of improved accuracy.

The measurements of third image size for all subjects are given in Table 1. The data of four subjects are plotted in Figures 5, a through d. Ordinate values are (left) millimeters of decrease in size of the third Purkinje image from its original size for a target 7.6 meters away and (right) diopters of accommodation approximately equivalent to the image size differences. The abscissa values are units of time in the dark. The data of these four observers, representing the kinds of variability found, are presented in the figures.

TABLE 1

OBJETIVE MEASUREMENTS OF ACCOMMODATION

Purkinje Image Size, in mm,
Over Six Readings

Subject	*Calibration Photo***	*0.50 Minute****	*5.0 Minutes*	*10.0 Minutes*	*15.0 Minutes*	*20.0 Minutes*
	1	2	3	4	5	6
WL	3.00	2.80	2.80	2.90	2.40	2.75
CA	4.50	4.10	3.70	3.70	3.75	3.45
NK	3.14	2.84	2.75	2.75	—	2.85
BC	4.01	3.50	3.31	3.18	3.07	3.18
JP	2.80	2.30	1.70	1.35	0.98	1.15
DS	4.48	3.88	2.35	3.03	3.25	2.70
GW	4.56	4.16	—	2.90	2.93	—
CP	3.90	3.70	—	—	3.55	3.40
KS	5.50	5.20	4.83	4.72	—	4.80
DF	3.25	2.75	2.48	2.50	—	
JS	2.53	2.55	2.15	2.00	2.15	2.20
JH	3.53	4.10	4.02	—	3.88	3.85
RN	2.89	2.54	2.36	2.32	2.40	2.10
NL	4.20	3.71	3.64	3.28	3.08	3.31

** 2 thriugh 6 were taken five minutes apart in the dark Columns. fixation at 7.6 meters.

*** Columns 2 through 6 were taken five minutes apart in the dark.

Table 2 contains measurements of third image size obtained on one subject at three-minute intervals over a time period of one and one-half hours. Figure 6 exhibits the plotted results of this data. Ordinate values represent (right) diopters of accommodation approximately equivalent to (left) image size change from the first reading, taken in room illumination. Abscissa units are time in the dark.

TABLE 2

LONG DURATION PURKINJE IMAGE MEASURES OF ACCOMMODATION

Minutes in the Dark	*Image Size in mm.*	*Size Difference from First Measure (Illuminated)*	Minutes in the Dark	Image Size in mm.	*Size Difference from First Measure (Illuminated)*
3	2.54	—	54	2.38	0.16
6	2.35	0.19	57	1.95	0.59
9	2.38	0.16	60	2.04	0.50
12	2.36	0.18	63	2.24	0.30
15	2.38	0.16	66	2.27	0.33
18	2.30	0.24	69	—	—
21	2.32	0.22	72	—	—
24	2.10	0.44	75	—	—
27	2.40	0.14	78	2.35	0.19
30	2.28	0.26	81	2.26	0.28
33	2.38	0.16	84	2.24	0.30
36	2.12	0.42	87	—	—
39	2.30	0.24	90	2.37	0.17
42	2.22	0.32	93	—	—
45	2.26	0.28	96	2.19	0.35
48	2.39	0.15	99	2.09	0.45
51	2.30	0.24	102	—	—

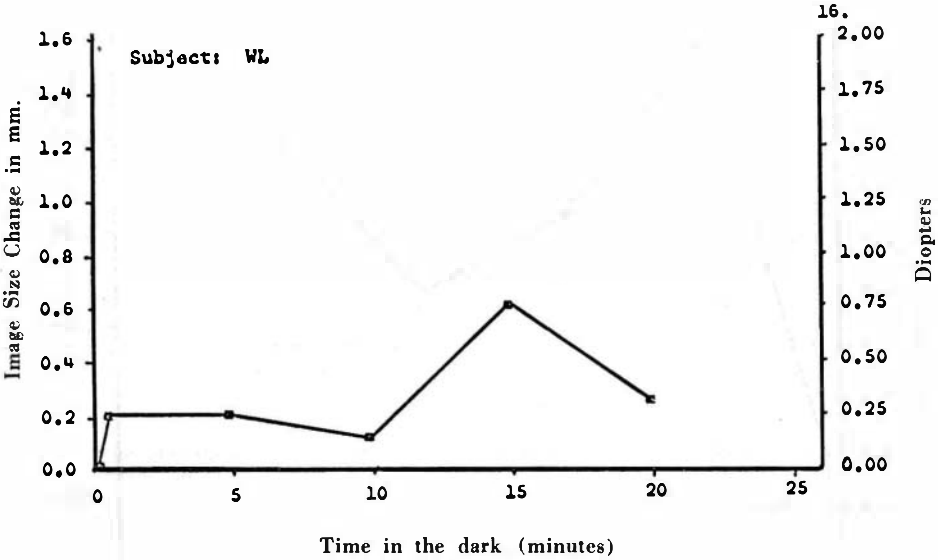
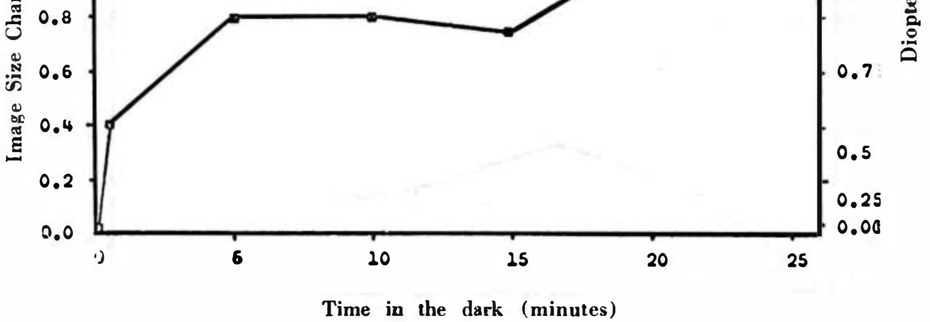


Figure 5a (above) and 5b (below): Objective Measurements of Accommodative Status in the Dark.



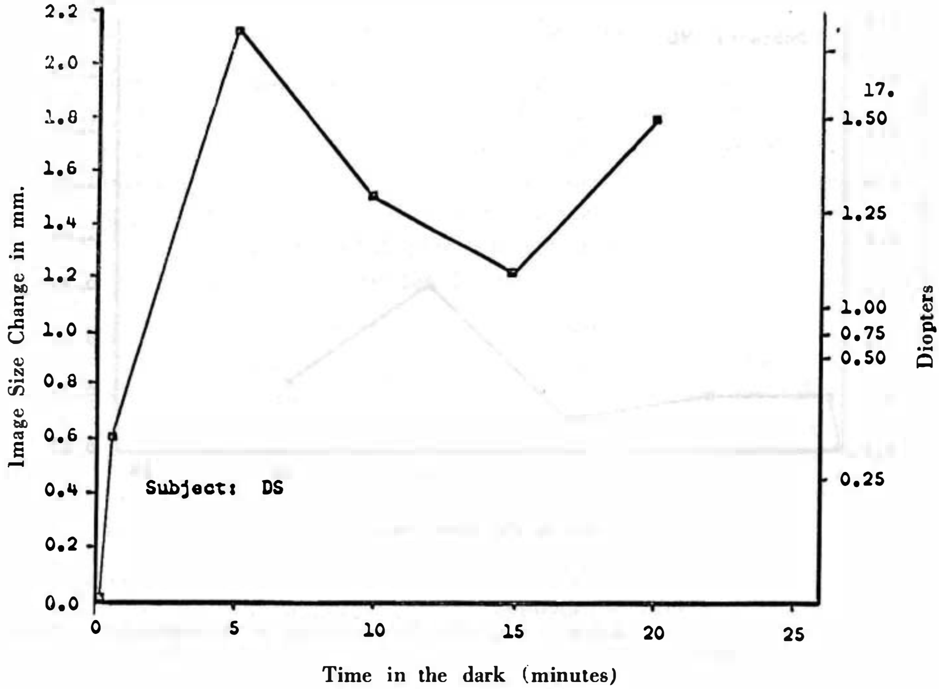
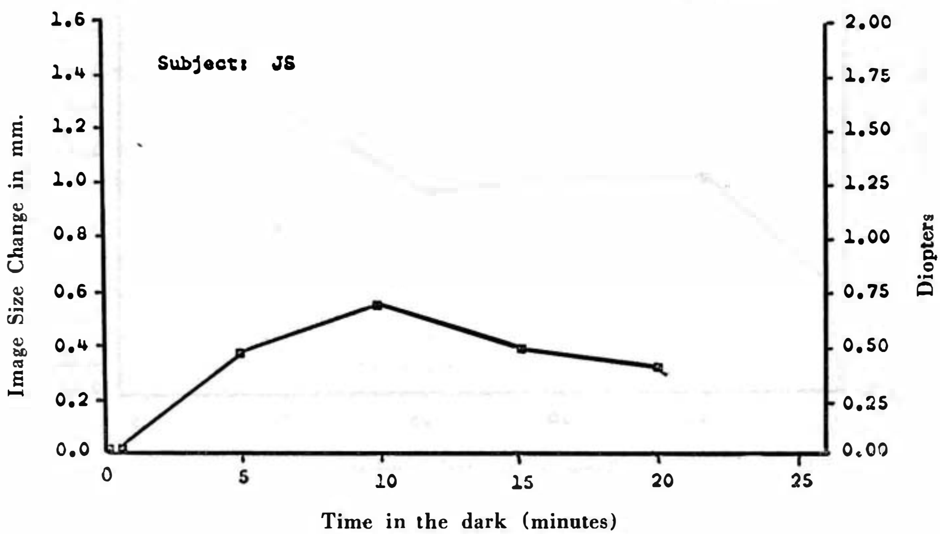


Figure 5e (above) and 5b (below): Objective Measurements of Accommodative Status in the Dark.



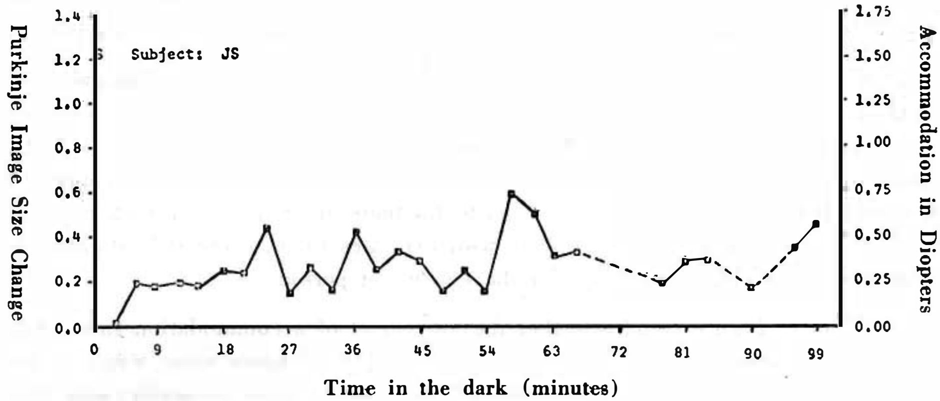


Figure 6. The amount and frequency of accommodative fluctuation during an extended period in the dark.

Discussion

Inspection of the 20 minute studies of accommodative behavior as plotted in Figures 5 a through d, reveals a define and consistant pattern of accommodative activity in the dark. In all cases, there is an immediate increase in accommodation upon cessation of the visual stimulus, which is noticeable as early as 30 seconds from the onset of the dark. From this point in time, responses appear to be individual. In certain cases, accommodation continues to increase to higher positive levels; others have moderate or no accommodative increase beyond the initial rise until much later in the time sequence. All subjects showed continual fluctuation of accommodation in varying amounts throughout the entire testing procedure. Mean accommodative level* at the end of 20 minutes in the dark for all subjects was 0.94 diopter. Individual values at the end of the 20 minute period were between 0.15 and 2.00 diopter, with fluctuations within the dark period in relative amounts to 0.62 diopter.

It must be recognized that measurements in these experiments were taken at 5 minute intervals. The possibility exists that more rapid fluctuations occur within each of these 5 minute intervals, and that artificial smoothing of the curves has resulted from the use of these arbitrary time steps.

Accommodative level, as this term is used herein, presumes ecuality of accommodative response and stimulus during the calibration procedure. Since the response might deviate from the stimulus by up to one half the dioptric value of the depth of focus of the eye and since most subjects tend to allow their responses to lag slightly behind the stimulus values, the nominal values assigned to the accommodative levels herein could reflect very modest underestimation.

To further investigate the time characteristics of fluctuation of accommodation in the dark one subject was selected to undergo the long duration accommodative study as previously described. See Figure 6. As was the case in nearly all the short duration studies, accommodation rose rapidly from zero at the onset of the dark period and quickly leveled off to fluctuate at each three minute interval around a mean value of 0.32 diopter with extremes to 0.75 and 0.25 diopter. It appeared to remain at this level for the entire test period.

The data of Figure 6 indicate that the movement of accommodation in a totally dark environment consists of rapid changes about a mean value wihch is individual for a given subjet. Qualitatively the data compare favorably with that of Heath [2], whose experimental instrument was the infra-red retinoscope. Quantitatively, however, the results of the present study were slightly lower than those found by Heath, which might be expected on the basis of the difference in instrumentation.

The mean accommodative level obtained in this extended test compares quite closely with the 0.32 diopter mean accommodative level obtained for the same subject in the short term accommodative study. Closer monitoring of accommodation does not apear to produce a real change in quantitative test results.

Summary and conclusions

Fourteen nearly emmetropic subjects between the ages of 20 and 41 were investigated to determine the be havior of accommodation at zero field luminance levels. The accommodations present when each subject was placed in a totally dark environment was measured objectively by means of photographing and measuring the size of the third Purkinje image reflected from the anterior lens surface. Calibration photographs taken with each subject fixating on and maintaining subjective clarity for various known distances allowed the third Purkinje image size change to be converted into diopters of accommodative change.

Two independent testing sequences were performed. In the first, objective measurements were taken at the beginning of a twenty minute period in the dark, and after each five minutes of that period. In the second, accommodation was objectively measured each three minutes over a total duration of ninety minutes in the dark. The second sequence was performed on one subject only.

Two outstanding facts became evident from analysis of the data of this study.

1. Objective measurements give unmistakable evidence of accommodative activity, as defined by deviation from clinical emmetropia, in the absence of visual stimulus at levels of zero field luminance. Ophthalmophakometric measurements yielded amounts of accommodation under these conditions closely approximating but slightly lower than those found by Otero, Campbell, and Heath in earlier investigations using similar methods. Considering the means of the 14 subjects in the present study, one finds an average accommodative level 0.94 diopter over a twenty minute period in the dark. There was, however, individual variation in which accommodation was as low as 0.3 diopter and as high as 2.25 diopters.

2. A continual fluctuation of accommodation was found to exist in the eye deprived of a visual stimulus for an extended period of time. Under these conditions, accommodation of the subject tested was found to vary between absolute amounts of 0.25 diopter to 0.75 diopter. The findings are similar in character to the long duration findings of Westheimer [5] (0.75 to 1.50 diopters) and Heath [2] (0.50 to 1.50 diopters) using the subjective optometer and infra-red retinoscope, respectively.

The fluctuation measured in this experiment could be described as that of an accommodative mechanism that is wandering, within limits, and is increased in its mean dioptric value as compared to photopic, structured field conditions, Certainly, its presence would raise serious question of the validity of the fixed focus concept of ampty field accommodative behavior that has often been mentioned in older literature.

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