

SHIFT IN THE PEAK OF THE PHOTOPIC STILES-CRAWFORD FUNCTION WITH MARKED ACCOMMODATION¹

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Abstract—In the unaccommodated eye the retinal receptors are aligned towards a point near the center of the exit pupil of the eye. In this study it is shown that marked accommodation caused a small but significant transient change in foveal retinal receptor orientation, largely in the horizontal meridian. This shift was evidenced by comparison of S-C function peak locations (which indicate the photoreceptor's central orientational tendency) in the entrance pupil of three subjects in both unaccommodated and accommodated states. On the basis of previous studies, it is suggested that this orientational change is the result of the asymmetrical retinal elongation in the horizontal meridian associated with accommodation. Thus, there is some evidence for a transient shear effect between the retinal receptors and the underlying interdigitating microfibrils of the pigment epithelium with strong accommodation. This tends to shift the peak of the Stiles-Crawford function nasally.

INTRODUCTION

Ciliary muscle contraction during marked accommodation causes the retina to elongate anteriorly (Luedde, 1927; van Alphen, 1961; Moses, 1970). This anterior elongation stretches the retina and increases its area (Enoch, 1973). Near the posterior pole, the stretch effect from above and below would be reasonably balanced. However, in the horizontal meridian the presence of the optic nerve head (where the retina is attached) unbalances the nasal and temporal pull at the posterior pole. The effects of the anterior extension of the retina during marked accommodation on monocular space perception were demonstrated in a series of classical bisection (or partition) experiments by Blank and Enoch (1973). It was found that marked accommodation induced substantial distortions in monocular space perception in the horizontal meridian. It was also shown that these distortions were largely due to retinal factors rather than to accommodative eye lens changes.

This study is designed to investigate the effect of this asymmetrical retinal elongation on retinal photorecep-

tor orientation. Retinal receptors have been shown to be aligned towards the center of the exit pupil (Laties and Enoch, 1971; Enoch and Laties, 1971; Enoch and Hope, 1972a, 1972b, 1973). The psychophysical technique employed to measure this effect in humans utilizes the photopic Stiles-Crawford (S-C) effect (1933), which allows one to evaluate the directional sensitivity of the retina. By studying the location of the peak of the directional sensitivity function, it is possible to draw inferences about the central orientational tendency of the receptors contained in the sampling area (Enoch, 1972; Enoch and Laties, 1971; Enoch and Hope, 1972a).

The finding that retinal receptors align with a point near the center of the exit pupil of the eye is especially impressive when one considers an array of millions of receptors only tens of microns long, remotely placed relative to the location of the pupillary aperture, a distance measured in tens of millimeters. It is highly unlikely that such a precision of alignment can be a chance occurrence. Considering the traumas and various forces to which the retina is exposed during life: gravitational, centrifugal, transretinal stresses (such as that occurring with accommodation), etc., it would seem that an active, ongoing mechanism for receptor orientation maintenance might be involved. The fact that orientational tendency was nearly constant across the subject population in Enoch and Hope's transretinal orientation studies (1972a, 1973), and that the peak varied only a few degrees across the retina of each individual (with respect to the exit pupil center) lends weight to this hypothesis.

At this point the mechanisms by which incorrect orientation is recognized, signalled and corrected can

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only be subject to speculation (e.g. Eakin, 1965; Enoch, 1972). However, certain anomalies of receptor orientation have been observed to recover (Fankhauser and Enoch, 1962; Enoch, Van Loo and Okun, 1973). Machemer [1968 (see also Enoch, 1969)] showed suggestive evidence for recovery of receptor orientation after experimental retinal detachment in the monkey. Mechanisms, then, may well exist which enable reorientation of disturbed receptors. In an attempt to define the presence and the nature of a possible orientational feedback system, it is clearly essential that factors influencing orientation be studied.

It is possible that the stretch of the retina with marked accommodation and the asymmetries in this stretch might serve to alter the precise receptor orientation. Coupled with this, the anterior extension of the retina might cause a shear effect to occur between the retinal receptors and the underlying interdigitating microfibrils of the pigment epithelium. Disruptions caused by marked accommodation should be evidenced by a displacement of the peak of maximum sensitivity of the S-C function, indicating a change in the orientational tendency of the receptors in the specific retinal area tested.

METHOD

Apparatus

Comparison of the location of peaks of the Stiles-Crawford function measured under accommodated and unaccommodated conditions was used as an indication of possible change in receptor orientation with accommodation. The "peak-finding" procedure described below was suitable for this comparison because it involved less time and substantial accommodation could only be maintained for short periods. However, the peak-finding method is valid only for subjects with normal, symmetrical S-C functions. Therefore, preliminary tests involved the determination of the entire Stiles-Crawford function by a more conventional method. The latter method requires two controlled Maxwellian-view light paths, with one beam passing through some fixed point in the entrance pupil and the other beam subject to translation across the entrance pupil (for details see Enoch and Hope 1972a, 1973). An increment threshold display was employed, with the flashing test field subtending a smaller angle ($12'$ of arc) at the entrance pupil than the background field ($4^{\circ} 24'$).

In both the "standard" S-C determinations and the peak-finding procedure it was necessary that the experimenter have careful control of the visual stimuli and the ability to very precisely relate observer position to stimulus array. The instrument includes a number of features which enable a high degree of precision in this respect. Remote controls allow the experimenter to locate the observer precisely. A bite bar and forehead press assembly was provided. Provision for direct continual observation of the subject's entrance pupil was possible by using an i.r. image converter. The entrance pupil display and images of the test stimuli delivered to the eye were projected on a reticule and caliper

plane (and in turn the reticule plane was imaged on the image converter). Thus entrance pupil, corneal reflexes and aperture images in the entrance pupil were continually subject to observation and fine control.

For the purposes of this study an arrangement of polaroid filters and an additional viewing target could be introduced, allowing a rapid technique for locating the peak of the S-C function. The technique is similar to one described by Enoch in his study of receptor amblyopia (1959). In this procedure, which will be referred to as the "peak-finding" (P-F) procedure, two identical round apertures, each $3/10$ mm in diameter and at a fixed separation of 2 mm, were placed in the aperture stop of one light path. The apertures were each covered by a linearly polarizing filter oriented at 90° to each other. The viewing target, located in the field stop, consisted of two parallel rectangles (each measuring $2^{\circ} 12' \times 1^{\circ} 50'$ and separated by $44'$ measured at the entrance pupil of the eye). These rectangles, with polaroids placed at right angles, allowed simultaneous presentation of two separated stimuli in the entrance pupil of the eye. The viewing target and the apertures could each be oriented horizontally or vertically. A variable polarizer, placed in the collimated light beam of the source and mounted so as to allow rotation, provided compensation for any inherent polarization of the optical path. A Kodak Wratten Filter No. 23A (red-orange) was placed in the visible beam⁵ and an i.r. filter was placed in the second path. The second light path was presented continuously. This enabled constant monitoring of the subjects position and control of the resultant corneal reflex through an i.r. image converter.

Observers

Three subjects were used. Subject F was a 22-yr-old near emmetropic male with normal uncorrected vision in both eyes (subject F in Blank and Enoch, 1973). He had an accommodative amplitude of 10 D in each eye. Subjects J and K were 17-yr-old female emmetropes. Their accommodative amplitudes were greater than 10 D.

Although the subjects successfully completed the assigned tasks, it was obvious during the accommodated P-F trials that a substantial physical expenditure was required. In future studies concentration on simplification of the subject's response task is indicated. A detailed description of the procedures used in training subjects to accommodate with a -9 D lens and in near total darkness will be reported elsewhere (Provine and Enoch, 1975).

Procedure

A prerequisite for the use of the peak-finding technique is that the subject have normal, symmetrical S-C functions. Hence S-C functions were initially determined by the standard method using foveal fixation and infinity focus (see Enoch and Hope, 1972a, 1973). When performing the peak-finding technique, the entrance pupil of the subject's eye was sharply focused (by means of z position adjustments). The corneal reflex from the infrared beam path (which was centered on the reticule) was used as the reference origin in this study, because its position is not altered by accommodation and associated iris aperture size changes. There is evidence that the center of the entrance pupil shifts with contraction (e.g. Enoch and Hope, 1972b) such as that occurring with accommodation. The corneal reflex caused by the i.r. beam path was visible in the i.r. viewer when the fixing left eye was translated slightly to the left (and the right eye to the right). A very small vertical translation was also indicated on occasion. The optimized corneal reflex appeared in the reticule pattern at the same position as the image of the aperture of

⁵ This served to eliminate blue polaroid transmission, to minimize chromatic aberration, and to provide added corneal reflex information to the i.r. system used for controlling eye position. Photopic response levels were used.

the centered test field. This suggests virtually normal incidence and reflection.

Peak-finding technique

The peaks found by the standard S-C method were compared to those found in the peak-finding procedure as a check of the validity of the latter.

For this procedure, the subject's eye was dilated by using a solution of 10% Ophthalmic Neo-synephrine which was diluted to 5 per cent with sterile distilled water. This drug provides significant mydriasis while only minimally affecting accommodation. One to three drops of the 5 per cent strength solution were instilled approximately 20 min before determining the S-C peaks to ensure that the accommodated pupil would not constrict to such a degree as to preclude the use of the peak-finding apparatus. Subjects were positioned and asked to steadily fixate a small spot of light located between the two rectangles of the peak-finding viewing target. The experimenter slowly translated the two apertures in tandem (at their fixed separation of 2 mm) across the diameter of the pupil in increments of approximately 0.125 mm. The determinations of horizontal S-C function peaks involved the horizontal translation of horizontally aligned apertures across the horizontal pupil diameter, determinations of vertical S-C function peaks involved vertical alignments and translations. At each position the subjects indicated which of the two parts of the target (each being illuminated by light from a different aperture)

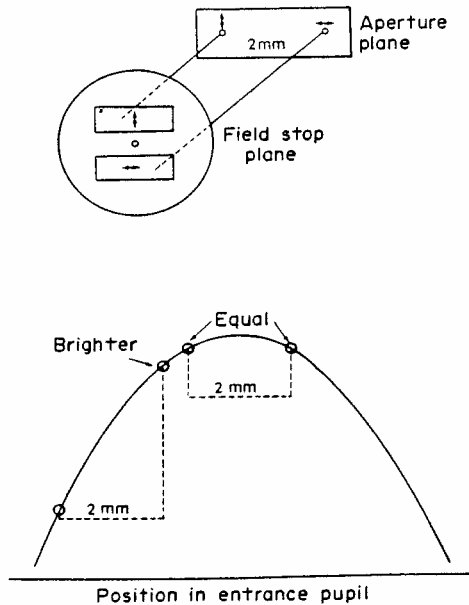


Fig. 1. This figure helps explain the P-F procedure. The two apertures are translated in tandem across the entrance pupil of the eye. The rectangle (in the field stop) illuminated by the aperture closer to the S-C peak will appear brighter to the observer. When the apertures are symmetrically disposed around the point in the entrance pupil corresponding to the S-C function peak, the bars which they illuminate will appear equal in brightness. The peak is therefore taken as the midpoint of the line connecting the two apertures at the location in the entrance pupil at which the bars appear equal in brightness. Polaroids separate the stimuli delivered by the two light paths.

appeared brighter. Provided the observers have normal, symmetrical S-C functions, and this was determined before this procedure was undertaken, the two bars should appear equal in brightness when the apertures are symmetrically disposed around the S-C peak. If one rectangle appears brighter, the image of its illuminating aperture in the entrance pupil is closer to the location of the peak (see Fig. 1).

Accommodation trials

As the peak-finding procedure involves much shorter test periods, and since marked accommodation is difficult to maintain over any extent of time, the accommodated S-C peaks were determined using the P-F procedure rather than the standard S-C method. During this part of the test the subjects performed the P-F test wearing strong minus soft contact lenses (-9 D Bausch and Lomb Soflens™ contact lens, Series N).

When accommodation is induced by lenses which are not located at the cornea, corrections for changes in aperture image location, entrance pupil location and size would be needed. With contact lenses, however, no correction is necessary since the distance of the lens from the pupil is so small (approx 3 mm) that it does not appreciably effect the plane of focus or position of the stimulus beam, as specified in this procedure. The fact that soft contact lenses take the shape of the wearer's eye prevents their significantly altering the lateral or vertical position of the corneal reflex. An adequate view of the infinity imaged stimulus display while wearing the contact lens required marked accommodation. The subjects were repeatedly reminded to have their bright-

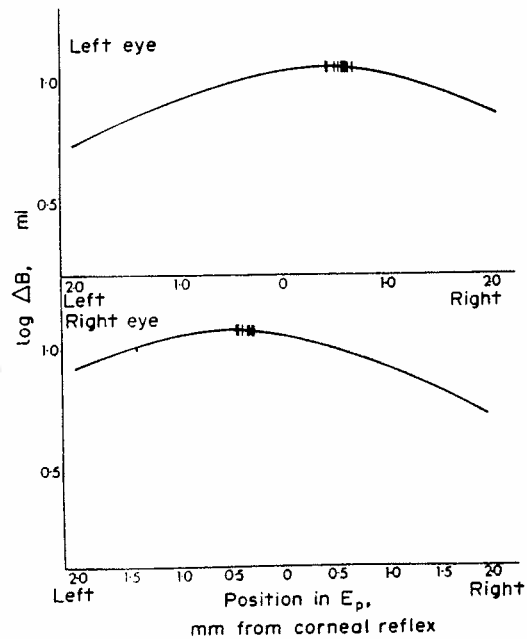


Fig. 2. The peak regions of subject F's horizontal S-C functions are shown. The curves were derived from data collected by the standard S-C method. The short vertical bars indicate the peaks located by the peak-finding method. A close agreement between the peaks found by the two methods is clearly evident. Note, the S-C function has been spread out in order to show the small variance in the peak finding determinations.

ness judgements coincide with their maximum accommodative effort. The experimenter was able to help in this synchronization by viewing the accommodative pupil contraction through the infrared image converter. Accommodated peaks and unaccommodated peaks were located during the same test session. Unaccommodated peaks were always found first in order to prevent residual accommodation from influencing the data.

The subjects repeated the P-F trials wearing a -0.50 D contact lens to determine the effect, if any, of merely wearing a contact lens (this lens would only minimally effect refraction). There is some difference in base curvature between the Bausch and Lomb -0.50 D and -9 D lenses. However, the differences caused by this factor should be less than the differences between wearing and not wearing a lens.

RESULTS

The S-C peak locations in the unaccommodated eye ascertained by the P-F method agreed closely with those found by the standard method for all observers. The central portion of the S-C curve of subject F and the location of peaks found by the P-F procedure are shown in Fig. 2. The peak finding results for this observer on both the unaccommodated and accommodated P-F trials are graphically illustrated in Fig. 3 (a and b). Means and standard deviations for all observers on the peak finding task for all conditions are presented in Table 1.

The results for subject F will now be described (Fig. 3 and Table 1). The changes in the peak location between trials with the -0.50 D lens and the trials with no lens (Table 2) were small but significant at the 0.05 level in the right eye and at the 0.01 level in both eyes (Student's t test was used as a measure of significance). In both the horizontal and vertical P-F trials for subject F, changes with the -0.50 D lens were in the same direction as the changes with the stronger lens in the left eye, and in the opposite direction in the right eye. It is not clear why these small changes occurred. No position adjustment was necessary to view the optimized corneal reflex in the i.r. viewer between the no lens and the lens trials. Because there was a significant effect on the peak with the -0.50 D lens and since this lens should induce only slight accommodation, the -0.50 D lens trials scores were compared with the -9 D scores (as well as comparing the no lens trials and the -9 D lens trials) to determine the magnitude of the peak shift with accommodation. The significance levels of the changes with accommodation are shown in Table 2. In interpreting these data it is important to keep in mind the precision of the S-C function measurements. A shift of the S-C peak in the entrance pupil of 1 mm reflects only a 2.5° difference in alignment measured at the retina.

The orientational changes with accommodation are shown in Table 2. The major peak shifts were in the nasal direction. Change in the location of peaks of the vertical S-C functions between the unaccommodated (no lens and -0.50 D lens) and accommodated (-9 D lens) trials were significantly smaller than the horizontal changes (Table 2). The difference between the mag-

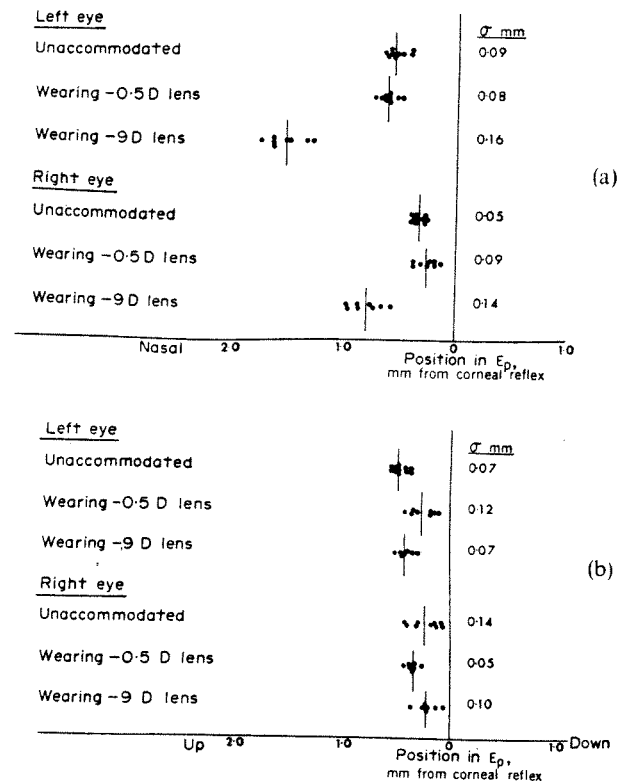


Fig. 3(a). This figure shows the results of the horizontal P-F trials performed by subject F. The vertical lines indicate the mean peak locations for a given test condition. All peaks found with and without accommodation were located to the nasal side of the corneal reflex (note, nasal in the left eye involves displacements to the right of the corneal reflex; in the right eye the peaks were located and displaced to the left of the corneal reflex). Standard deviations (σ) are also shown. (b) This figure shows the results of the vertical P-F trials. The vertical lines show the means of the judgements for a given test condition. All S-C peaks were located above the corneal reflex for subject F.

nitude of the horizontal peak shifts as compared to the vertical shifts were significant (0.01 level).

The peak finding data for subject J are generally comparable to those described above for subject F. Subject J showed no significant peak shifts between the no lens and the -0.5 D lens condition in the horizontal meridian. Accommodation resulted in a large and significant ($P < 0.001$) shift in the S-C peak when compared with the values obtained in the no lens and the -0.5 D lens conditions. No significant differences were found between any of the peaks obtained in the vertical meridian. Subject J showed extremely steady fixation, even during the very strenuous accommodation task, and no position adjustments were needed to optimize the corneal reflex between the no lens and the lens trials.

As was found with subjects F and J, subject K showed a large and significant ($P < 0.001$) nasal shift

Table 1. Positions of Stiles-Crawford function peaks and standard deviation

	Horizontal		Vertical	
	Mean (mm)	S.D. (mm)	Mean (mm)	S.D. (mm)
Subject F				
LEFT EYE				
No lens	0.57 right*	0.09	0.48 up	0.07
-0.50 D contact lens	0.64 right	0.08	0.27 up	0.12
-9.00 D contact lens	1.54 right	0.16	0.42 up	0.07
RIGHT EYE				
No lens	0.35 left	0.05	0.22 up	0.14
-0.50 D contact lens	0.26 left	0.09	0.36 up	0.05
-9.00 D contact lens	0.79 left	0.14	0.21 up	0.10
Subject J				
RIGHT EYE				
No lens	0.22 right	0.35	0.10 up	0.16
-0.50 D contact lens	0.38 right	0.55	0.24 up	0.25
-9.00 D contact lens	1.58 left	0.31	0.22 up	0.41
Subject K				
RIGHT EYE				
No lens	0.21 left	0.37	0.23 down	0.44
-0.50 D contact lens	0.34 left	0.45	0.41 up	0.56
-9.00 D contact lens	1.13 left	0.46	0.07 up	0.28

*Right means to the right hand side of the center of the pupil. In the left eye this would be nasal to the center of the pupil.

Table 2. S-C peak shifts, orientational changes and levels of significance

Score comparison	Meridian	Peak change*	Orientalional change	Significance of change
Subject F				
LEFT EYE				
No lens vs -0.50 D	Horizontal	0.07 mm N	0.175	0.01
	Vertical	0.21 mm D	0.525	0.01
No lens vs -9 D	H	0.97 mm N	2.425	0.01
	V	0.06 mm D	0.15	N.S.
-0.50 D vs -9 D	H	0.90 mm N	2.25	0.01
	V	0.15 mm U	0.375	0.05
RIGHT EYE				
No lens vs -0.50 D	H	0.09 mm T	0.225	0.05
	V	0.14 mm U	0.350	0.01
No lens vs -9 D	H	0.44 mm N	1.10	0.01
	V	0.01 mm U	0.025	N.S.
-0.50 D vs -9 D	H	0.53 mm N	1.33	0.01
	V	0.15 mm D	0.375	0.05
Subject J				
RIGHT EYE				
No lens vs -0.50 D	H	0.16 mm N	0.400	N.S.
	V	0.13 mm U	0.325	N.S.
No lens vs -9 D	H	0.65 mm N	1.625	0.001
	V	0.19 mm U	0.475	N.S.
-0.50 D vs -9 D	H	0.24 mm N	0.600	0.001
	V	0.02 mm U	0.050	N.S.
Subject K				
RIGHT EYE				
No lens vs -0.50 D	H	0.13 mm N	0.325	N.S.
	V	0.64 mm U	1.600	0.001
No lens vs -9 D	H	0.93 mm N	2.325	0.001
	V	0.30 mm U	0.750	0.001
-0.50 D vs -9 D	H	0.80 mm N	2.000	0.001
	V	0.34 mm U	0.850	0.01

* N = Nasal. T = Temporal. U = Up. D = Down.

N.S. = Not significant.

of the S-C peak during accommodation when compared with either the results obtained with no lens or with the -0.5 D lens (Table 1). The horizontal P-F trials revealed no significant differences between the no lens and the -0.5 D lens condition. In contrast, a large and significant ($P < 0.001$) upward peak shift was found between the no lens and the -0.5 D lens conditions in the vertical meridian. This difference was probably due to a prismatic effect which resulted from a small vertical displacement of the -0.5 D contact lens on the cornea. No such lens effect was observed in the horizontal meridian. Small but significant differences in peak location were detected in the vertical meridian between the S-C peak during accommodation and those obtained in the no lens and the -0.5 D lens conditions. Interpretation of this data set is made difficult because vertical displacements of the -0.5 D and the -9 D contact lenses may have yielded spurious peak shifts in the vertical meridian. The results obtained in the vertical meridian do not detract from the finding that subject K showed a marked nasal horizontal shift of her S-C peak during accommodation.

DISCUSSION

These data clearly suggest that accommodation can cause a small but significant transient change in photoreceptor orientation, at least in the horizontal meridian.

In order to understand what this peak shift of the S-C function with accommodation represents, the effects of two accommodative retinal factors must be distinguished. First, the peak of maximum receptor sensitivity may be displaced by a shear effect between the retina and the pigment epithelium-choroid. Secondly, the peak of the Stiles-Crawford function may be displaced by retinal translation with marked accommodation; the latter effect will be referred to as a "pseudo-shear". With contraction of the ciliary muscle the retina-choroid is elongated towards the ora from the posterior pole. This translation will cause a slight shift in apparent receptor orientation as projected to the pupil plane *even in the absence of a shear effect*. Calculations of the new exit pupillary intercept of the translated receptor axis (assuming simple translation about the center of the retinal sphere and no orientation correction) show that for retinal displacements at the fovea of up to 30' of arc, the change in receptor orientation (as projected to the entrance pupil) would be no more than 0.1 mm (see Appendix for calculations and illustrations of the effect). Since this value is calculated for a rather substantial retinal shift, the effect of "pseudo-shear" on the position of the S-C peak can be safely discounted.

The magnitudes of the horizontal peak displacements show that in addition to the pseudo-shear effect another mechanism seems to be operating. Although accommodative eye lens factors may contribute to the effect, these optical changes do not seem to account for it to any great degree. This conclusion seems war-

ranted by the small size of the vertical S-C peak changes with accommodation. This limited effect of accommodation in the vertical meridian was also found in monocular bisection experiments (Blank and Enoch, 1973). Since eye lens changes are not limited to one meridian it would seem that if eye lens changes were instrumental in producing the effect, much less difference in monocular bisection distortions and S-C peak shifts would have been expected between the horizontal and vertical meridians.

In the present study we have an effect which seems to be a manifestation of local inequalities in retinal-choroidal stretch. In retinal regions other than the area immediately around the ora, the retina and pigment epithelium (which overlies the choroid) lie in close contact with a pattern of interdigitation occurring between the retinal receptors and the microfibrils of the pigment epithelium. Experimental retinal detachment studies have shown that there is a viscoelastic type force between the pigment epithelium and the retina (Zauberman and deGuillebon, 1972; deGuillebon, Tribonniere and Pomerantzeff, 1971; deGuillebon and Zauberman, 1972). When tension is exerted by ciliary muscle contraction, the pigment epithelium and the retina should ride forward with the choroid, each elongating to the degree determined by their own elastic properties. If local differences in elasticity exist it seems to follow that a shear effect might develop in their region of contact. The degree of shearing would also depend on the local strength of adhesion between the retina and the pigment epithelium and possibly on the distribution of the choroidal and retinal vasculature. Nasalward shifts of the horizontal S-C peaks were found in both eyes in subject F and in the right eyes of subjects J and K, indicating that the shearing effect caused the receptor axes to become directed more nasally. Local variations across the retina may well exist—particularly if one tests on the near and far side of the blind spot.

The exact amount of accommodation which produces this change in receptor orientation in our subjects cannot be stated with certainty, as no provision was made in the apparatus to determine the exact effective power of the minus soft lens and the test target as stimuli for accommodation. A nominal stimulus of X diopters does not necessarily mean the observer will exert X diopters of accommodation. Subject F's accommodative response was determined external to the apparatus; he was found to be accommodating to within 0.5 D of the lens power indicated.

Another variable which further prohibits accurate quantification of the subject's accommodative response was the effect of the mydriatic agent (one to three drops of 5% Ophthalmic Neo-synephrine). Determinations of the accommodation nearpoint made at various time intervals after application showed little measurable effect of the mydriatic on accommodation during testing. However, it is not possible to state with certainty the effect of the mydriatic on accommodation at any given moment during a trial

or on a different date. There is also a reduction in the depth of field and the exposing of the peripheral lens with pupil dilation which, during accommodation, is subject to various aberrations.

The unfamiliar experience of wearing a soft contact lens could also have affected the data. As an additional control situation, the observers repeated the tests wearing a -0.50 D lens. Since the change in refraction due to this lens is small, any resultant peak shifts should be due to the experience of having a foreign object on the cornea and possible to the failure of the soft lens to parallel the cornea (this might shift the corneal reflex slightly). Although sometimes significant, the changes in the peak locations between trials with and without the -0.5 D lens were generally, but not always (see subject J), quite small [see Fig. 3 (a and b)] and no trends were evident in the direction of this shift.

In spite of the problems discussed, wearing a contact lens did allow the induction of substantial accommodation in three observers. Even if the lens failed to induce maximum accommodation, the retinal effect should still be present. In bisection experiments with subject F, a nearly linear relationship was found between the amount of accommodation and the degree of induced monocular space distortion (distortions in this type of test are also manifestations of inequities of retinal-choroidal stretch but over a larger retinal region). The soft contact lens did not noticeably affect the position of the corneal reflex, the reference origin used in this study.

If our subject population represents the population at large, and there is in fact a resultant nasal shift of the S-C peak with accommodation, this could possibly be a cause for the general tendency of peaks of S-C functions to be displaced slightly nasally with respect to the center of the entrance pupil. Unlike eye movements, for example, which occur in opposing directions (presumably with some reasonably equal frequency) the retinal deformations due to accommodation and associated shear should always be in the identical direction during life (barring some changes in the adhesion of the retina or in the choroid and changes due to presbyopia). If the return of the retina to its accommodation-relaxed state reflects a more gradual release in tension, the nasal bias could be explained. As receptor orientation is disturbed by accommodation, there may be a passive or active mechanism for helping in the restoration of receptor alignment on the release of accommodation. Thus, further study of accommodation induced retinal change and recovery are clearly indicated.

This experiment indicates that more attention should be given to effects of accommodation on the retina, particularly because all such information is of value when considering factors influencing the adhesion of the retina to its substrate, e.g. see Spencer, Straatsma and Foss (1969), and Lempke and Pischel (1966). Similarly, one must consider the location and nature of accommodative phosphenes (Czermak in

von Helmholtz, 1962). In addition, the retinal stretching evidence in this study and the suggested resulting shear effect should be investigated further with respect to the effects of these actions at different ages and in the presence of different refractive errors.

Finally, the effect here is of importance to future research on photoreceptor orientation. In order to discover if and how the system detects, signals and corrects faulty photoreceptor orientation, it is important to evaluate those factors which might serve to influence retinal orientation. The experimental design of the present investigation is the first measurement of the nature and magnitude of accommodation's effect on photoreceptor alignment. Hopefully, these findings will be of help in the future determination of the nature of a possible photoreceptor orientation feedback mechanism.

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The resultant displacement of the projection of the long axis of the receptor is to the side of the pupil opposite to the side of retinal translation. Thus, if the temporal retina is considered and the retina advances anteriorly, the translation of the pupillary projection ("pseudo-shear") of the receptors will be nasally in the exit and entrance pupils of the eye. The magnitude of the "pseudo-shear" effect is small, of the order of 0.1 mm, for $\Delta\phi = 0.5^\circ$. It is doubtful whether such a change could be detected in measures of the Stiles-Crawford effect.

When θ_2 , θ_3 and θ_1 go to zero at the posterior pole, special treatment is needed. However, the resultant anticipated magnitudes are again small.

In summary, simple displacement of the retina results in a "pseudo-shear". The estimated magnitude of the effect for $\Delta\phi = 0.5^\circ$ is small, and probably could not be detected within the measurement variance of the Stiles-Crawford effect. Thus, we can deduce that measured changes are due to true rather than "pseudo-shear".