S Afr Optom 2005 **64** (1) 26 – 30

RESEARCH NOTE

Dark refraction shift with allowance for astigmatism

WDH Gillan* and WF Harris**

Optometric Science Research Group, Department of Optometry, University of Johannesburg, PO Box 524, Auckland Park, 2006 South Africa
<wdhg@na.rau.ac.za>

Abstract

Purpose: To show that the dark refraction shift (dark focus) is a more complicated phenomenon than implied when presented as spherical.

Methods: Fifty autorefractor measurements of refractive state of the right eye were obtained in light and dark conditions. Multivariate methods were used to analyze the data and stereo-pair scatter plots, polar meridional profiles and other means of presenting results are used to show important characteristics of the dark refraction shift.

Results: The complexity of the dark refraction shift is indicated by stereo-pair scatter plots showing the amount of stigmatic and antistigmatic variation that occurs in light and dark conditions. The mean dark refraction shift is presented in a complete manner including all three components of refractive state. The greater variance and covariance under dark conditions is clearly shown by the term-by-term dark-light variance-covariance ratio and polar profiles of variance and covariance.

Conclusions: The dark refraction shift is a more complicated phenomenon than implied by representations as purely spherical in nature.

Keywords: dark refraction shift, dark focus, multivariate methods, stigmatic, antistigmatic, polar profiles.

The refractive state of the human eye is rarely purely stigmatic (spherical) in nature. Accommodation can induce astigmatic change in refractive state[1]. However, as far as we are aware, studies investigating the dark focus report findings in which the dark focus is recorded as spherical only. In many instances the technique used to measure the dark focus is limited to spherical measurements[2-13], in other instances infra-red optometers are used but only the nearest equivalent sphere is recorded[14-17], and in other studies no mention is made of how the infra-red optometer measurements are used to produce spherical-only recordings[18-24]. In some studies the researchers deliberately disable the axis rotation mechanism of the optometer and use a single, usually the vertical, meridian to determine the dark focus[25-28]. Apart from the use of standard deviation and standard error of the mean[4-8, 10-11, 14-15, 20-22], no other approach is used to evaluate the characteristics of the variation of multiple measurements of refractive state under dark conditions.

We prefer the term dark refraction shift to the traditional term dark focus. Formally we define the dark refraction shift to be $\triangle F$ where $\triangle F = F_D - F_L$.

F_D and F_L are dioptric power matrices and represent refraction in the dark and light respectively. We believe that aspects of the dark refraction shift have been missed in the past because incomplete, purely spherical measures of the dark refraction shift have been reported. They include: the extent of stigmatic and antistig-

*DipOptom MPhil DPhil(RAU) CAS(NewEnCO) FAAO FIACLE
**BSc(Eng)(Witwatersrand) MS PhD(Minnesota) BOptom(RAU) BSc(Hons)(Unisa) FAAO FRSSAf
This paper results from research conducted for the degree DPhil under the guidance of Professor WF Harris at the Rand Afrikaans University.
Received 5 January 2005; revised version accepted 26 February 2005

matic variation, a complete measure of variance and covariance of refraction in the dark, the relationship between light and dark condition variance and covariance as well as the changes in the characteristics of variation occurring in light and dark conditions. The purpose of this note is to illustrate these phenomena.

Method

Twenty individuals acted as subjects in this study, 10 were aged between 21 and 35 years of age (pre-presbyopes) and the other 10 were aged between 40 and 65 years of age (presbyopes). The data from only one subject (aged 21) is used in this article in the interests of brevity. This subject was selected because her findings highlighted interesting aspects of the data. All subjects were treated according to the tenets of the Declaration of Helsinki and all subjects were volunteers and gave informed consent after the research protocol had been explained to them. All subjects were selected after undergoing a battery of screening tests. A Hoya AR 550 autorefractor was used to take 50 measurements of refractive state of the right eye under two conditions, the light condition where the instrument target and the room environment were fully illuminated and the dark condition where the instrument target and room illumination were largely eliminated. Each subject spent five minutes in darkness before the dark condition measurements were taken. The autorefractor was set to measure refractive state in steps of 0.01 D and the vertex distance was set at zero.

Power is represented as the symmetric dioptric power matrix

$$\mathbf{F} = F_{st}\mathbf{I} \quad F_{or}\mathbf{J}\ F_{ob}\mathbf{K}$$

where $\mathbf{I} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $\mathbf{J} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ and $\mathbf{K} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$.

F_{st}, F_{or} and F_{ob} are the stigmatic, ortho-antistigmatic and oblique antistigmatic coefficients of the power respectively. On the face of it F_{st}, F_{or} and F_{ob} are equivalent to M, J_0 and J_{45} respectively defined by Thibos and coworkers[29]. However, the analysis here has a different basis; in contrast to their power vectors it is in terms of dioptric power matrices. Graphical representations of the matrices in symmetric dioptric power space are constructed using axes representing scalar multiples of **I**, **J** and **K**. Means are obtained as the arithmetic mean of the matrices. Variances and covariances are calculated for F_{st}, F_{or} and F_{ob}. All data collected were analyzed using methods developed by Harris[30-35] and software developed by Malan[36] , Harris and Rubin[37].

Results

Table 1 gives the mean refractive state (of 50 autorefractor measurements) for the light and dark condition in conventional spherocylindrical terms as well as in terms of the stigmatic (F_{st}) and the ortho- (F_{or}) and oblique (F_{ob}) anti-

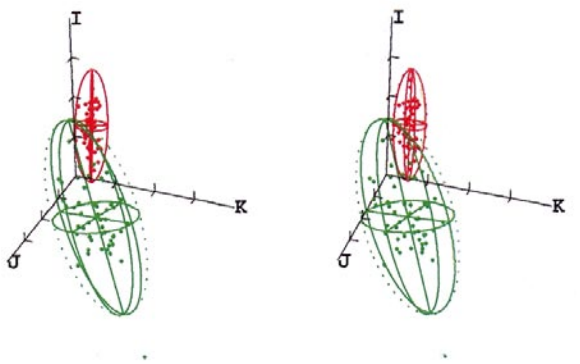


Figure 1. (a) Stereo-pair showing light (red) and dark (green) condition measurements. Included are the 95% distribution ellipsoids. The origin is [0 0 0] D and tick intervals are 0.25**I**, 0.25**J** and 0.25**K** D. The difference in size and positioning of the two clusters show the changes in refractive state and its variation under the two stimulus conditions.

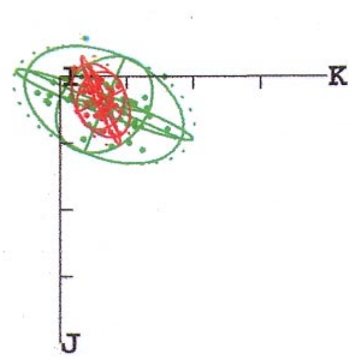


Figure 1. (b) Scatter plot showing the data viewed along the stigmatic axis. Only a single set of axes are presented showing light (red) and dark (green) condition data. The orientations of the major axes of the two ellipsoids are noticeably different, indicating the change in antistigmatic variation in response to the stimulus conditions.

Table 1. Mean refractive state for light and dark conditions and mean dark refraction shift given in complete conventional and component notation.
(* The ortho-antistigmatic mean seems incorrect but round-off has resulted in this apparent discrepancy).

	Sph	Cyl	Axis	F_{st}	F_{or}	F_{ob}
Light	0.57	– 0.35	29	0.40	0.09	0.15
Dark	0.02	– 0.39	29	– 0.17	0.11	0.16
Mean dark refration shift	– 0.55	– 0.04	20	– 0.57	0.01*	0.01

Table 2. Variances and covariances in D^2 of the coefficients of power; s_{11}, s_{22}, and s_{33} represent the stigmatic (F_{st}), the ortho-antistigmatic (F_{or}) and the oblique antistigmatic (F_{ob}) coefficients respectively. s_{12}, s_{13} and s_{23} represent the stigmatic-ortho-antistigmatic, stigmatic-oblique antistigmatic and ortho-oblique antistigmatic covariances respectively.

Condition	s_{11}	s_{22}	s_{33}	s_{12}	s_{13}	s_{23}
Light	0.0116	0.0037	0.0016	– 0.0029	– 0.0006	0.0010
Dark	0.0420	0.0063	0.0147	– 0.0010	– 0.0084	0.0036

Table 3. The term-by-term dark-light variance-covariance ratios are shown. r_{11}, $r_{22,}$ and r_{33} indicate the ratio of the stigmatic, ortho-antistigmatic and oblique antistigmatic variance components respectively. r_{12}, r_{13} and r_{23} indicate the stigmatic-ortho-antistigmatic, stigmatic-oblique antistigmatic and ortho-oblique anstigmatic covariance ratios respectively.

Condition	r_{11}	r_{22}	r_{33}	r_{12}	r_{13}	r_{23}
Ratio	3.6	1.7	9.2	0.33	13	3.5

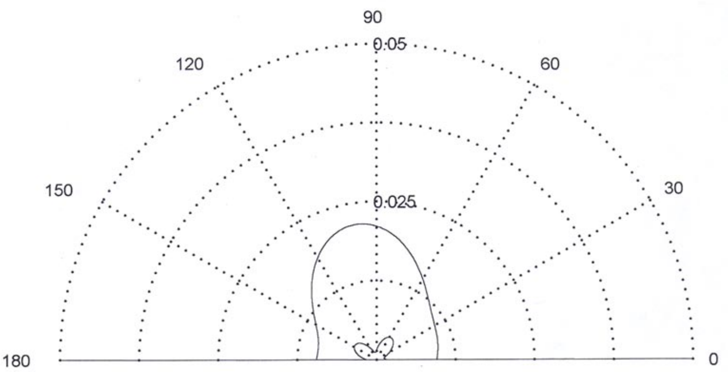
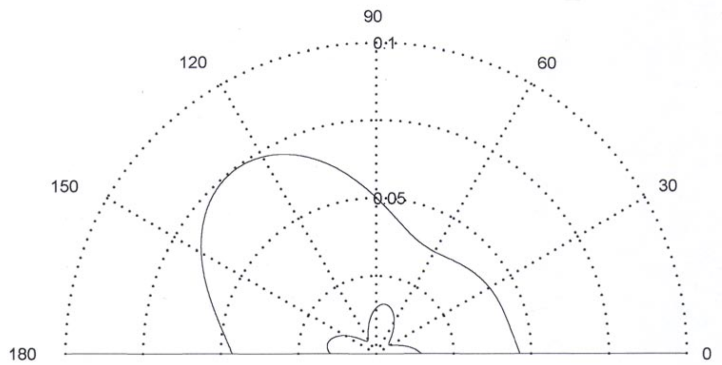


Figure 2 (a). Polar meridional profiles of curvital (larger, outer profile) and torsional (smaller, inner profile) variance are shown. (2a) Light condition. The meridian of maximum curvital variance is close to the vertical meridian.



(b) Dark condition. The meridian of maximum curvital variance is approximately 1300. The scale in (b) is twice that in (a).

stigmatic coefficients. Also included in Table 1 is the mean dark refraction shift.Figure 1a is a stereo-pair showing 50 measurements of refractive state taken in the light (red) and dark (green). Included for each cluster of measurements are the 95% ellipsoidal surfaces of constant probability density (distribution ellipsoids). The origin of the axes is [0 0 0] D and the tick intervals are 0.25**I** D, 0.25**J** D and 0.25**K** D.

The stereo-pair can be fused by converging the eyes to a point in front of the page, this way the three-dimensional character of the data can be appreciated.

Important aspects of Figure 1a to note are each ellipsoid is elongated parallel, or almost parallel, to the stigmatic axis showing that mainly stigmatic (spherical) variation took place during the measurements. The dark cluster (green) is larger than the light cluster (red) showing the increased variation taking place in the dark, in both the stigmatic and antistigmatic direction (indicated by the larger waist of the green ellipsoid). The dark refraction shift is indicated by the lower positioning of the green cluster (in this orientation) relative to the red cluster.

Table 2 gives the vectorized variance and covariance matrices for the light and dark measurements, units are D^2. Table 2 gives the only complete representation of the variance and covariance that exists between the components of refractive state. An important indicator of the difference in variance and covariance that occurred between light and dark measurements is the term-by-term dark-light variance-covariance ratio shown in Table 3.

The important aspects of Table 3 are: the stigmatic variance ratio, 3.6, and the oblique variance ratio, 9.2. The stigmatic ratio shows that there was about 3.6 times more stigmatic or spherical, variation occurring in measurements taken in the dark compared with those taken in the light (seen as the greater stigmatic elongation of the green cluster in Figure 1a) while the oblique antistigmatic ratio shows about nine times more variation in the dark indicating the increased antistigmatic variation (seen as the larger waist of the green ellipsoid in Figure 1a). The increased oblique antistigmatic variation is seen in Figure 1b and is shown by the larger green ellipsoid that is elongated roughly parallel to the oblique antistigmatic, **K**, axis. Figure 2 shows polar meridional profiles of variance for the light (Figure 2a) and dark (Figure 2b) data. The outer, larger profiles indicate the curvital variance across meridians and the smaller, inner profile the torsional variance across meridians of the eye. Figure 2a has the largest curvital variance close to the vertical meridian, a phenomenon that has been seen previously and is thought to be due to the blink process. However, Figure 2b shows the greatest curvital variance close to the 130^{o} meridian.

The scale is also larger in Figure 2b, indicating the greater amount of variance occurring under dark conditions, and is also shown in Figure 1a and Tables 2 and 3. It is not clear why the meridian showing the greatest variance should change under light and dark conditions.

Discussion

Presenting the results of research[2-28] involving the dark refraction shift in terms of only a spherical component of refractive state is incomplete; such results give no indication of the complexity of the phenomenon. This article has presented the dark refraction shift of a single individual and has emphasized aspects of the phenomenon other than only the spherical component. In particular it shows that the dark refraction shift has an antistigmatic component, that variation occurs in both the stigmatic as well as antistigmatic components and that stigmatic and antistigmatic variation increase under dark conditions.

Acknowledgements

This note is based, in part, on research supported under grant No 2053699 to WF Harris from the National Research Foundation. We thank Leoni Joubert for helpful comments.

References

1. Ukai K, Ichihashi Y. Changes in ocular astigmatism over the whole range of accommodation. *Optom Vis Sci* 1991 **68** 812-818.
2. Owens RL, Higgins KE. Long-term stability of the dark focus of accommodation. *Am J Optom Physiol Opt* 1983 **60** 32-38.
3. Ebenholtz SM. Accommodative hysteresis: a precursor for induced myopia. *Inv Ophthalmol Vis Sci* 1983 **24** 513-515.
4. Miller RJ, Wesner MF, Pigion RG, Martin KD. Overaccommodation, underaccommodation and the clinical phoropter: a study of instrument myopia and related effects. *Am J Optom Physiol Opt* 1984 **61** 293-303.
5. Pigion RG, Miller RJ. Fatigue of accommodation: changes in accommodation after visual work. *Am J Optom Physiol Opt* 1985 **62** 853-863.
6. Ebenholtz Sm. Accommodative hysteresis: relation to resting focus. *Am J Optom Physiol Opt* 1985 **62** 755-762.
7. Accommodative hysteresis: influence on closed loop measures of far point and near point. *Inv Ophthalmol Vis Sci* 1987 **28** 1246-1249.
8. Miller RJ, Takahama M. Effects of relaxation and aversive visual stimulation on dark focus accommodation. *Ophthal Physiol Opt* 1987 **7** 219-223.
9. Fisher SK, Ciuffreda KJ, Levine S. Tonic accommodation, accommodative hysteresis and refractive error. *Am J Optom Physiol Opt* 1987 **64** 799-809.
10. Miller RJ. Effect of pupil size on dark focus accommodation. *Ophthal Physiol Opt* 1988 **8** 227-228.
11. Miller RJ, Takahama M. Arousal-related changes in dark focus accommodation and dark vergence. *Inv Ophthal Vis Sci* 1988 **29** 1168-1178.
12. Fisher SK, Ciuffreda KJ, Bird JE. The effect of stimulus duration on tonic accommodation and tonic vergence. *Optom Vis Sci* 1990 **67** 441-449.
13. Ritter AD, Huhn-Beck H. Dark focus of accommodation and nervous system activity. *Optom*

Vis Sci 1993 **70** 532-534.
14. McBrien NA, Millodot M. Differences in adaptation of tonic accommodation with refractive state. *Inv Ophthal Vis Sci* 1988 **29** 460-469.
15. Rosenfield M, Gilmartin B. Effect of target proximity on open-loop accommodative response. *Optom Vis Sci* 1990 **67** 74-79.
16. Chiu NN, Rosenfield M. Tonic accommodation, tonic vergence and surround propinquity. *Ophthal Physiol Opt* 1994 **14** 290-292.
17. Andre JT, Owens RL, Owens DA. Dark focus values measured by retinoscopy: a clinical chart review. *Optom Vis Sci* 1998 **75** 903-908.
18. Post RB, Johnson CA, Tsuetaki TK. Comparison of laser and infrared techniques for measurement of the resting focus of accommodation: mean differences and long-term variability. *Ophthal Physiol Opt* 1984 **4** 327-332.
19. Post RB, Johnson CA, Owens DA. Does performance of tasks affect the resting focus of accommodation? *Am J Optom Physiol Opt* 1985 **62** 533-537.
20. Bullimore MA, Gilmartin B. Tonic accommodation, cognitive demand and ciliary muscle innervation. *Am J Optom Physiol Opt* 1987 **64** 45-50.
21. Bullimore MA, Gilmartin B. Aspects of tonic accommodation in emmetropia and late-onset myopia. *Am J Optom Physiol Opt* 1987 **64** 499-503.
22. McBrien NA, Millodot M. The relationship between tonic accommodation and refractive error. *Inv Ophthalmol Vis Sci* 1987 **28** 997-1003.
23. Jiang B, Woessner WM. Dark focus and dark vergence: an experimental verification of the configuration of the dual-interactive feedback model. *Ophthal Physiol Opt* 1996 **16** 342-347.
24. Mordi JA, Ciuffreda KJ. Static aspects of accommodation: age and presbyopia. *Vis Res* 1998 **38** 1643-1653.
25. Johnson CA, Post RB, Tsuetaki TK. Short-term variability of the resting focus of accommodation. *Ophthal Physiol Opt* 1984 **4** 319-325.
26. Schor CM, Tsuetaki TK. Fatigue of accommodation and vergence modifies their mutual interactions. *Inv Ophthal Vis Sci* 1987 **28** 1250-1259.
27. Miwa T. Instrument myopia and the resting state of accommodation. *Optom Vis Sci* 1992 **69** 55-59.
28. Miwa T, Tokoro T. Relation between the dark focus of accommodation and refractive error-a cycloplegic study. *Optom Vis Sci* 1993 **70** 328-331.
29. Thibos LN, Wheeler W, Horner D. Power vectors: an application of Fourier analysis to the description and statistical analysis of refractive error. *Optom Vis Sci* 1997 **74** 367-375.
30. Harris WF. Algebra of sphero-cylinders and refractive errors, and their means, variance and standard deviation. *Am J Optom Physiol Opt* 1988 **65** 794-802.
31. Harris WF. Squaring the sphero-cylinder, the equivalent of squaring the refractive power matrix. *Ophthal Physiol Opt* 1988 **8** 458-459.
32. Harris WF. Representation of dioptric power in Euclidean 3-space. *Ophthal Physiol Opt* 1991 **11** 130-136.
33. Harris WF. Astigmatism. *Ophthal Physiol Opt* 2000 **20** 11-30.
34. Harris WF. Optical effects of ocular surgery including anterior segment surgery. *J Cat Ref Surg* 2001 **27** 95-106.
35. Harris WF, Van Gool RD. Curvital and torsional dioptric power and their polar profiles across meridians. *S Afr Optom* 1998 **57** 3-17.
36. Malan DJ. Dioptric power data analysis: computer implementation of graphical methods with clinical examples. *S Afr Optom* 1993 **52** 84-90.
37. Rubin A. *Surfaces of constant visual acuity in symmetric dioptric power space.* DPhil thesis, Johannesburg: Rand Afrikaans University, South Africa, 2001.