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Refractive behavior under light, dark and cycloplegic conditions

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Introduction

When visual stimulation is absent from the human visual system, either by means of complete darkness or a Ganzveld, the accommodative system postures at an intermediate distance known as the dark focus of accommodation[1-5]. What essentially happens in stimulus-free conditions is that there is a myopic shift of the refractive state of the eye, termed the dark refraction shift by Gillan and Harris[6], which occurs as a result of accommodation taking place[1, 5]. The changes that occur in mean refractive state as well as the variation of the measurements under light and dark conditions have been investigated previously[7-11] (For a detailed exposition of the dark refraction shift the reader is referred elsewhere [7-11].)

Cycloplegia is "paralysis of the ciliary muscle and the power of accommodation, usually accompanied by a dilated pupil"[12]. Tropicamide (Mydriacyl), usually used as a mydriatic, can be used as a cycloplegic of short duration[13]. Because accommodation is paralyzed under cycloplegic conditions one might expect that the dark refraction shift is reduced or perhaps eliminated. Changes in refractive state under different stimulus conditions can consist of at least two aspects. Firstly, the mean refractive state can vary (the dark refraction shift) while the second change that may occur is variation of the refractive state resulting in a cluster of measurements about some mean. Gillan[14] has shown, in a single subject, that the amount of variation occurring in measurements of refractive state under cycloplegia does not reduce significantly. Intuitively one might expect that cycloplegia would reduce the amount of variation occurring in measurements of refractive state. Variation can occur in three components of refractive state namely the stigmatic component, the ortho-antistigmatic component and the oblique antistigmatic component. Antistigmatic accommodation can be defined as components of accommodation that are orthogonal to stigmatic accommodation in symmetric dioptric power space[15]. Classically, astigmatic accommodation has been thought to be possible and has been defined[12]. However, many optometric and ophthalmologic texts state that it is rare, not clinically significant or does not occur[16-21].

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The aim of this study is to investigate refractive behavior of the visual system under various stimulus conditions (namely light, dark and cycloplegic conditions) with an emphasis on the antistigmatic components.

Method

Five female optometry students, referred to as HP, AN, BB, KN and MR respectively aged between 19 and 22 years, acted as subjects in this study. Subjects were fully aware of the research protocol and volunteered to act as subjects in this study. All subjects were free of any observable ocular pathology and none had any history of ocular surgery at the time the study was conducted. A Nidek ARK-700 autorefractor was used to take measurements of unaided refractive state under the three experimental conditions (light, dark and cycloplegic). The autorefractor was set to measure refractive state in 0.01 D steps. A printout of ten consecutive measurements was done (as the instrument memory is limited to 10 measurements) and this procedure was carried out five times per measurement session (giving a total of 50 measurements for each subject under each experimental condition). All measurements were taken of the right eye of each subject. The autorefractor was refocused after each measurement.

An initial 50 measurements of refractive state were taken under lit conditions (light conditions). All lights were switched on in the experimental environment including the target within the autorefractor. Each subject was positioned in front of the autorefractor with their chin on the chin rest and the forehead against the forehead rest. The subjects were instructed to look at the balloon situated at the end of the road that made up the internal target of the instrument. Following the initial 50 measurements each subject then spent five minutes sitting in front of the instrument, in a relaxed manner, in complete darkness. Five minutes in complete darkness has been shown to be an adequate amount of time for the accommodative system to posture at the dark focus of the eye[22]. The target inside the autorefractor was switched off leaving only

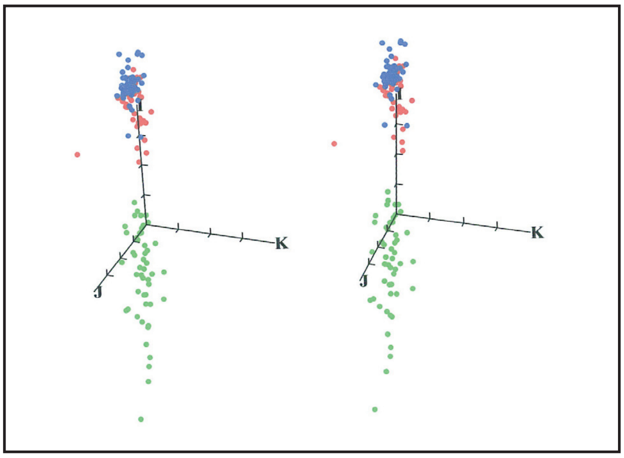

Figure 1: Stereo-pair scatter plot of fifty light, dark and cycloplegic (red, green and blue respectively) measurements from subject HP. The origin is at **−I** D.

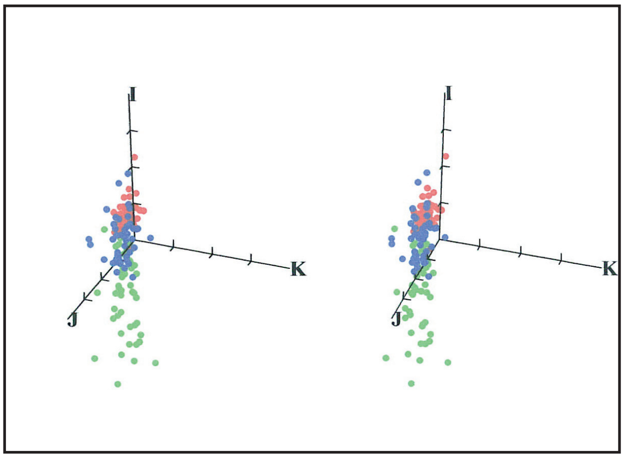

Figure 2: Scatter plot of fifty light, dark and cycloplegic (red, green and blue respectively) measurements from subject AN. Axis origin is set at **0** D. A decreased amount of dark refraction shift is noticed compared to that seen in Figure 1.

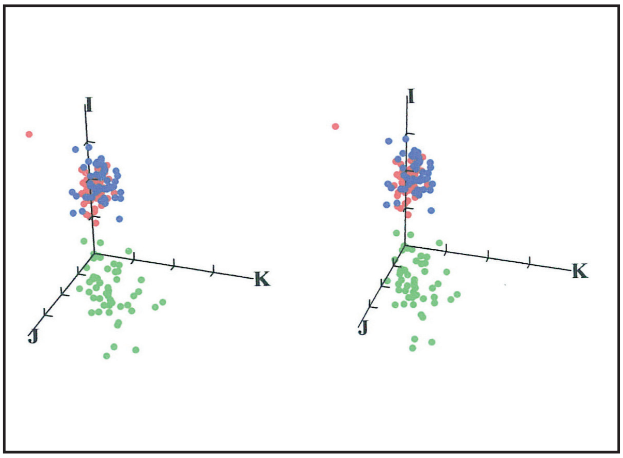

Figure 3: Scatter plot of fifty light, dark and cycloplegic (red, green and blue respectively) measurements from subject BB. Axis origin is set at **−I** D. More antistigmatic variation is seen in the cycloplegic measurements as indicated by the increase in the waist of the green data points.

a small, dimly illuminated red target (the infrared source). This red target aids the subject in maintaining fixation in a target-free environment while not influencing the accommodative system in any way[22]. The subjects were instructed to look through the red target and not at it. Following the five minutes in complete darkness, the subject was repositioned in front of the instrument so that the 50 measurements of refractive state, in complete darkness, could be conducted (dark conditions). Once the dark condition measurements were completed a single drop of Mydriacyl was instilled into the right eye of the subject. The subject then waited for 30 minutes to allow for an adequate state of cycloplegia to develop. The subject then spent another five minutes in compete darkness before the last 50 measurements of refractive state were taken (cycloplegic conditions).

All data were then entered into a computer and analysed making use of software developed by Harris and Malan (and modified by Rubin). Further statistical analysis was conducted by RJE to investigate the antistigmatic nature of the data.

Results

Figures 1 to 5 show stereo-pair scatter plots of the data collected from the five subjects. Data collected under light conditions, dark conditions and cycloplegic conditions are represented on each set of axes by red, green and blue points respectively. The origin of each stereo-pair varies for each subject and will be indicated later. **I, J** and **K** represent the powers **I, J** and **K D** relative to the origin. Each scatter plot is a stereo-pair that can be fused by converging the eyes to a point in front of the page whereby a three dimensional percept of the data can be obtained. Each point shown represents one measurement of refractive state.

Figure 1 shows the data collected from subject HP. The red data points show some stigmatic variation (indicated by the elongated nature of the data points roughly parallel to the stigmatic, **I**, axis) in the measurements with less antistigmatic variation (shown by the narrow waist of the data). The antistigmatic nature of the data will be discussed in more detail later. The green points represent the data collected in the dark and show an elongated cluster that has also shifted in a myopic (more negative) direction. The length of the green cluster also indicates the amount of stigmatic variation that was taking place while the measurements were being collected. The myopic shift of the green data points seen in Figure 1 represents the dark refraction shift. The blue points, showing the cycloplegic data, are positioned closer to the light data indicating that the accommodative system is unable to produce the changes in accommodation that result in the dark refraction shift. A single red point is seen to the left of the axes (in this orientation) and might indicate an outlier. The origin of the axes repre-

Table 1. Means of measurements taken from all subjects in conventional as well as component notation. L, D and C indicate means of data collected under light, dark and cycloplegic conditions respectively.

Subject	Condition	Sph	Cyl	Axis	FI D	FJ D	FKD
AN	L	0.28	−0.51	107	0.03	−0.21	−0.15
	D	−0.22	−0.53	110	−0.49	−0.21	−0.17
	C	0.13	−0.53	110	−0.14	−0.20	−0.17
BB	L	−0.52	−0.15	92	−0.60	−0.07	−0.05
	D	−1.19	−0.19	76	−1.28	−0.08	0.04
	C	−0.49	−0.16	81	−0.57	−0.08	0.02
HP	L	0.12	−0.12	177	0.05	0.06	−0.01
	D	−1.28	−0.18	172	−1.37	0.09	−0.03
	C	0.24	−0.15	171	0.19	0.05	−0.02
KN	L	−2.21	−0.20	17	−2.31	0.08	0.06
	D	−2.63	−0.46	6	−2.86	0.22	0.05
	C	−2.28	−0.46	4	−2.40	0.12	0.02
MR	L	−2.74	−0.52	8	−3.00	0.25	0.07
	D	−3.97	−0.45	15	−4.20	0.20	0.11
	C	−3.06	−0.43	15	−3.28	0.19	0.11

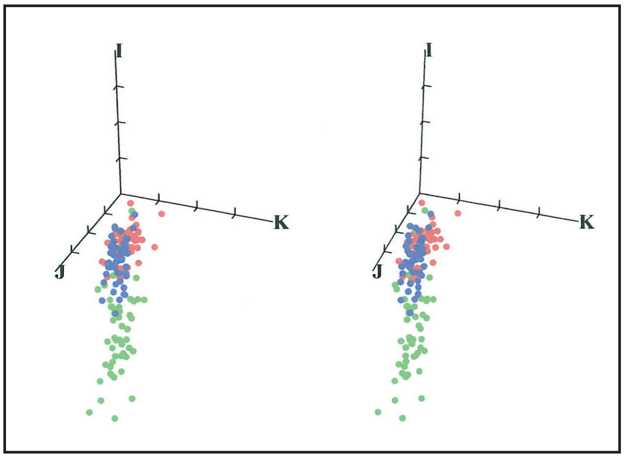

Figure 4: Scatter plot of fifty light, dark and cycloplegic (red, green and blue respectively) measurements from subject KN. Axis origin is set at −2**I** D.

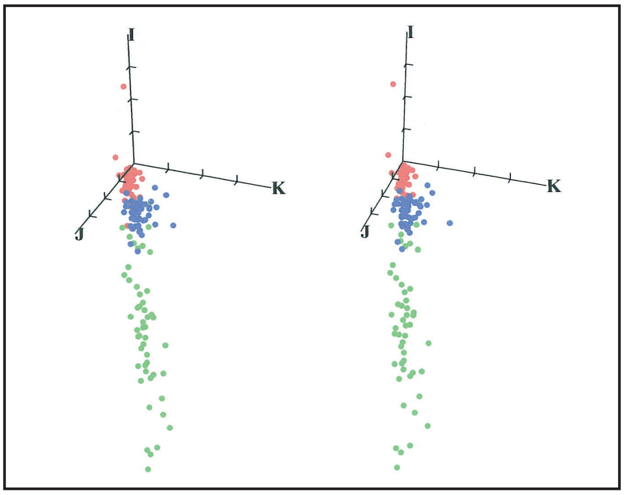

Figure 5: Scatter plot of fifty light, dark and cycloplegic (red, green and blue respectively) measurements from subject MR. Axis origin is set at −3**I** D.

sents the power −**I** D.

The data collected from subject AN are shown in Figure 2. The extent of the stigmatic variation of the light condition data (red points) in Figure 2 is less than that seen in Figure 1, nevertheless, an obvious dark refraction shift has taken place under dark conditions and this is confirmed in Table 1. There has also been an increase in the amount of spread of the dark data shown by the elongation of the green data along the stigmatic axis.

Figures 3 to 5 (subjects BB, KN and MR respectively) present a similar picture to that seen in Figures 1 and 2. The common aspects of figures 1-5 are the following:

1. All figures show some stigmatic variation of all the data points (indicated by the elongation of the data approximately parallel to the stigmatic, **I**, axis).
2. All figures show the dark refraction shift that occurs when subjects are placed in the dark. The dark refraction shift is indicated by the myopic shift of the green data points.
3. An increase in the stigmatic variation of the measurements is shown in the data collected in the dark (green points).
4. Under cycloplegic conditions the dark refraction shift dissipates (shown by the hyperopic shift of the data collected under

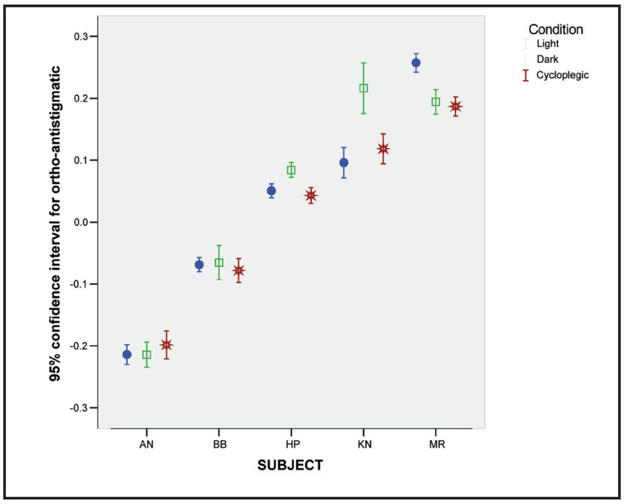

Figure 6: 95% confidence intervals for mean ortho-antistigmatic variables by condition and subject

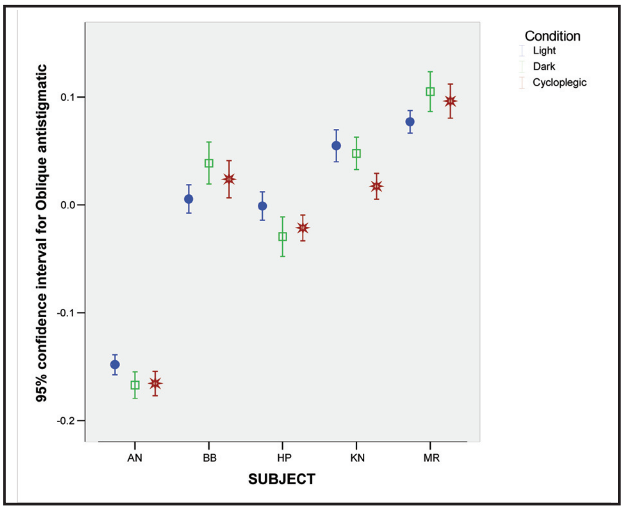

Figure 7: 95% confidence intervals for mean oblique antistigmatic variables by condition and subject

Table 2. Number of observations (after removal of outliers), means and standard deviations of the vector of observations of the antistigmatic component of refractive state. M = Mean. SD = Standard deviation

Subject	Condition	Numbers of observations after removal of outliers	Ortho-antitigmatic		Oblique antistigmatic	
			M/D	SD/D	M/D	SD/D
AN	L	49	−0.214	0.056	−0.148	0.032
	D	45	−0.214	0.068	−0.167	0.041
	C	46	−0.198	0.076	−0.166	0.038
BB	L	49	−0.069	0.040	0.006	0.046
	D	48	−0.065	0.095	0.039	0.067
	C	50	−0.078	0.068	0.024	0.061
HP	L	48	0.051	0.039	−0.001	0.045
	D	49	0.084	0.042	−0.029	0.064
	C	49	0.043	0.044	−0.021	0.042
KN	L	48	0.096	0.085	0.055	0.051
	D	48	0.216	0.142	0.048	0.052
	C	50	0.119	0.085	0.017	0.042
MR	L	49	0.257	0.052	0.077	0.037
	D	49	0.194	0.069	0.105	0.065
	C	48	0.187	0.053	0.096	0.055

Table 3. Multivariate test for the equality of the vector of means of the three conditions for the five subjects. df = degrees of freedom

Subject	Wilks'Lambda	F	df	Error df	p-value	Effect size (Eta)
AN	0.936	2.286	4	272	0.06	0.182
BB	0.935	2.448	4	286	0.047	0.182
HP	0.802	8.274	4	284	<0.005	0.322
KN	0.723	12.480	4	284	<0.005	0.386
MR	0.689	14.512	4	284	<0.005	0.412

Table 4. Table of between-subject effects for each of the variables within the antistigmatic component by subject

Subject	Dependent Variable	Type III Sum of Squares	Mean Square	Df	F	Sig.	Effect size (eta)
AN	Oblique antistigmatic	0.011	0.005	2	3.837	0.024	0.23
BB	Oblique antistigmatic	0.027	0.013	2	3.947	0.021	0.23
HP	Ortho-antistigmatic	0.047	0.023	2	13.456	<0.005	0.40
	Oblique antistigmatic	0.021	0.01		3.937	0.022	0.23
KN	Ortho-antistigmatic	0.394	0.197	2	17.168	<0.005	0.44
	Oblique antistigmatic	0.039	0.02		8.375	<0.005	0.32
MR	Ortho-antistigmatic	0.146	0.073	2	21.244	<0.005	0.48
	Oblique antistigmatic	0.02	0.01		3.551	0.031	0.22

cycloplegic conditions. Blue data points). This is a result of the paralysis of the ciliary muscle induced by the cycloplegic. This hyperopic shift also lends support to the hypothesis that the dark refraction shift is a result of the activity of the accommodative system.

Table 1 contains the means of 50 measurements taken under light (L), dark (D) and cycloplegic (C) conditions for each subject. Means are represented in conventional as well as component notation. The dark refraction shifts (predominantly stigmatic) for each subject can be seen when comparing the stigmatic components of the light and dark data means.

The findings discussed above are not new and similar findings have been published elsewhere[7-9]. An important aspect of the results of this investigation involves the antistigmatic components (ortho-antistigmatic and oblique antistigmatic) of accommodative change under the various conditions and these will be presented below.

To ascertain the extent to which the vector of antistigmatic components (consisting of the ortho-antistigmatic and oblique antistigmatic components) differs under the three conditions, that is, light, dark and cycloplegic, MANOVA was used on the measurements of each of the subjects respectively. However, the presence of outlier values (cf. Figure 1 to 5) threatens the assumption of bivariate normality associated with the use of this technique[23]. For each subject, outliers in the two-dimensional space were identified by examining Mahalanobis distances[23]. Measurements considered to be outlier values were removed. The resulting number of observations, after removal of the outlier values appears in Table 2 for each of the conditions and each of the subjects.

The means (M) and standard deviations (SD) for the vector of observations of the antistigmatic component in each of the conditions for each of the subjects are shown in Table 2. The null-hypothesis that the vector of means of the antistigmatic component is the same in the three conditions is rejected at the 1% level of significance for subjects HP, KN and MR, at the 5% level of significance for subject BB but only at the 10% level of significance for subject AN (Table 3). For subjects HP, KN and MR, effect sizes (as measured by eta) are moderate (between 0.3 and 0.5) while they are small (between 0.1 and 0.3) for both subjects BB and AN. From Table 4 it is deduced that for subjects BB and AN, the null-hypothesis of equal population means is only rejected for the oblique antistigmatic variable of the antistigmatic component while it is rejected for both the oblique antistigmatic and ortho-antistigmatic variable for the other three subjects.

Post-hoc comparisons (utilising either the Scheffe or the Dunnett T3 comparisons, depending on whether the assumption of equality of variance can be assumed) revealed that for the ortho-antistigmatic component the mean in dark conditions differed significantly from both the mean for the light and cycloplegic conditions for two of the subjects (HP and KN) while the mean in the light conditions differed significantly from both the dark and the cycloplegic conditions for one of the subjects (MR). The means for the other two subjects did not differ significantly. Differences per subject are graphically depicted in Figure 6.

For the oblique antistigmatic component, the mean in light conditions differed significantly from the mean in dark conditions for three of the subjects (BB, HP and MR) while the mean in the cycloplegic condition differed significantly from both the mean in the light and in the dark conditions for one subject (KN). These differences are illustrated in Figure 7.

Discussion

The typical changes in refractive behavior induced by dark and cycloplegic conditions, namely the dark refraction shift and the increased variation in measurements under dark conditions, have been reiterated in this study. The investigation into the effects of the different stimulus conditions on the antistigmatic components of accommodation is new. Based on the above results, it is evident that although the null-hypothesis of equal vectors of means in the three conditions is rejected at the 10% level of significance or more stringent level of significance for four of the five subjects in this study, the differences between the three conditions are not consistent over these subjects. Hence, the results are inconclusive. However, what has been shown in this study is that antistigmatic components of accommodation appear to be present under all stimulus conditions, something that classic texts suggest is very rare or non-existant[16-21]. Further research needs to be done to elucidate antistigmatic components of accommodation more completely.

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