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The refractive behaviour of the human eye under different ambient lighting conditions

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Background: Adjustment of the ocular accommodative system is an important phenomenon allowing for optimal vision at different distances.

Aim: The study compared the refractive behaviour of the human eye under different ambient lighting conditions for different target brightness.

Setting: Auto-refraction measurements were taken of the participants in the Department of Optometry at the University of Johannesburg.

Methods: Five African participants from a single ethnic group aged between 20 years and 25 years, had 40 successive auto-refractor (Nidek AR 610) measurements taken on the right eye of each participant in a bright and dark room using the illuminated and dark targets (LL and DL); dark target in the illuminated and dark room (LD and DD).

Results: A change in the refractive state of all participants was observed on LL and LD, except for one, who experienced myopic shifts. The largest significant difference in the variance-covariances and the means was approximately 2.40 dioptre (D). The other participants' shifts in means were approximately the same and varied between 1.00 D and 1.50 D stigmatic shift. For the DL to DD conditions all participants, except for one, underwent a hyperopic shift of about 0.50 D.

Conclusion: The refractive behaviour of the human eye appears to be dependent on ambient light conditions as well as target illumination or luminance.

Contribution: The study is scientific and clinical, and focuses on changes in refractive behaviour under different lighting conditions, falling within the scope of the journal. Key insights are that there is a change in the refractive behaviour of the eye under different ambient conditions.

Keywords: refractive behaviour; auto-refractors; luminance; photoreceptors; depth of focus; stereo-pair scatter plots.

Introduction

The amount of light entering the eye through the pupil is mostly controlled or regulated by the iris. The process involves the reaction of the pupillary sphincter and dilator muscles, the two involuntary iris muscles required to control the amount of light travelling to the retina. Control of the amount of light and change of the pupil diameter is effective on the illuminance and sharpness of retinal images impacting the control of the wavefront aberrations.[1] When light enters the eye in dark conditions (scotopic vision), the pupil increases in size to allow more light to enter, while in bright conditions (photopic vision) the pupil constricts.[2] The retina has two types of photoreceptors: rods and cones. The rods are found in the paracentral and peripheral retina and operate the best in scotopic conditions but cannot detect colour. Cones found only in the macula region of the retina are responsible for colour vision and operate best in photopic conditions. Visual acuity (VA) refers to the clarity of vision (resolving power), but technically rates a person's ability to recognise fine detail.[3] It is also dependent on optical and neural factors that involve the sharpness of the retinal image within the eye, the health and functioning of the retina, and the sensitivity of the interpretative faculty of the brain.[4] Room illumination influences VA and refractive behaviour.[5] The number of parameters used for testing VA has been standardised including distance charts and luminance of the test chart.[6] Variations in room lighting conditions used must also be taken into consideration. This research investigates how these changes in room illumination and target brightness within an auto-refractor might affect the refractive state of the eye. The reason for such differences may be related to optical influences

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such as ocular accommodation and night myopia, therefore the purpose of this article was to compare the refractive behaviour of the human eye under different ambient lighting conditions for different target brightness in an auto-refractor.[7]

Literature review

Visual acuity is defined as the ability to distinguish detail that is measured as the reciprocal of the visual angle (minutes of arc) subtended at the eye by the smallest detail of an object that can be discriminated.[8] The minimum angle of resolution (MAR) for VA of the human eye is usually better than 1 min of arc. There are different types of VA, namely minimum-perceptible acuity that refers to the smallest target an eye can detect, such as a dot and minimum distinguishable acuity, which is the most measured acuity, that refers to the smallest detail the eye can detect. Dynamic VA is the ability to discriminate when the target object is moving and minimum separable acuity refers to the smallest lateral displacement of two lines that can be detected, with the lines positioned end-to-end.[8]

The pupil, which acts as an aperture stop of the eye, constricts in response to luminance increments in the stimulus field. However, it has also been observed that it also constricts or dilates in response to changes in the spatial frequency composition of the stimulus.[9] This observation is interesting because spatial gratings are formed by luminance decrement and increments; in the absence of any luminance increments, it is assumed that the spatial changes can cause pupillary constriction. In photopic conditions, pupil acuity not only correlates with but also is as high as the perceptual acuity of the observers. The pupil constriction in the presence of a spatial pattern in both scotopic and photopic conditions was documented by Young et al. in their study where they concluded that the amplitude of the pupillary constriction decreases as the illuminance of the spatial pattern is reduced. They also concluded that the similarity between the perceptual and pupillary acuity is not specific to photopic illuminance levels.[10]

Receptors that convert light stimuli to nerve impulses are called rods and cones, which are found predominantly in the retina periphery. There is a misconception that only one receptor functions at night or day, which is not true as both rods and cones function over a wide range of light intensity levels and function simultaneously at intermediate levels of illumination. Mesopic vision is a transition zone of photopic and scotopic vision, and there is a process in which the eye adjusts from high-luminance setting to low-luminance, which is known as dark adaptation.[11] The fovea is the portion of the retina responsible for the highest resolution of VA, and it possesses a high concentration of cones in the rod-free macula lutea.[8,12]

Pupil constriction or dilation is important for the clarity of images for photopic and scotopic vision. Constriction of the pupil in bright illumination was found to decrease the amount of light scatter and increase VA. A study was conducted by Maqsood[13] on 25 healthy subjects (with 49 healthy eyes) with different spherical equivalent refractive errors ranging from –6.75 dioptre (D) to 0.50 D. In this study, the effects of small-scale illumination levels were investigated with the pupil size measured using Visante Optical Coherence Tomography. The findings of this study demonstrated that ambient illumination levels from high to low can cause an increase in pupil size with the presence of refractive error appearing to have no extra influence. The dilation of the pupil allows more light to enter the eye, thus enabling one to see better in the darkness.[9,13]

In a study conducted by Hickenbotham, Tiruveedhula and Roorda,[14] visual performance and depth of focus were compared using adaptive optics corrected distance visual acuity (CDVA) values and mean VA above 3.0 D including the range of defocus using three adaptive optics–corrected profiles. Pupil size reduction in bright illumination was found to increase VA because of the increased depth of focus, reducing the effect of refractive error on the blur of the retinal image. In this study on visual performance and depth of focus, they compared adaptive optics to CDVA values and mean VA over a 3.0 D range of defocus. Three optics–corrected profiles: 2.0 mm, 3.0 mm, and 5.0 mm pupils with −0.274 µm of spherical aberration were used. They concluded that the reduction of the pupil size was found to increase VA because of increased depth of focus, thus reducing the effect of refractive error on the blur of the retinal image. However, it will be interesting to investigate the effect on the visual system when targets of varying illumination, are seen under different room illuminations to detect the impact on the refractive status.

The concept of night myopia is associated with the changes of refractive error referred to as dark focus that can take place because of reduced illumination.[15] Koomen, Scolnik and Tousey[16] concluded that the shift to myopia in darkness referred to as 'night myopia' is because of the aberrations of the eye and not as a result of ocular accommodation. Abdul et al.[6] conducted a pilot study on one participant to investigate the behaviour of the refractive status of the eye under different light conditions and for different target brightness in an autorefractor. The participant was left in a bright room for about 45 min to adapt to the bright conditions, thereafter auto-refractor readings were taken using a brightly illuminated target, and then using a dimmed target. On the second day of the study, the patient was left in a dark room for the same period and the same procedure was repeated except that the room was kept dark. The results were then compared, and it appeared that using a dimmed target in a bright room resulted in a spherical decrease of about 0.20 D in the measured refractive error. However, in dark conditions, there was a slight change in the refractive status that had no clinical significance. It was found that darkening the room resulted in a small hyperopic shift of the refractive status. The limitation to the generalisation of this study's findings was because of the limited number of participants involved in the study. Therefore, the aim of this study was to compare the refractive behaviour of the human eye under different ambient lighting conditions for a slightly larger sample of eyes.

Research methods and design

Design

The design of the study is quantitative and descriptive.

Sample selection

All participants were African university students selected using convenience non-random sampling. Five participants, one male and four female, participated in the study. Their ages ranged between 19 years and 25 years with a mean age of 21.6 years.

Inclusion criteria

- Participants between the ages of 19 years and 25 years.
- No predetermined refractive errors were required.
- No systemic diseases.
- Participants were not on any form of medication that may affect the results.

Exclusion criteria

- Participants with any ocular or systemic conditions or diseases.
- Participants younger than 18 years old and older than 25 years old.

Data collection

Data collection took place within the Department of Optometry at the University of Johannesburg, Doornfontein campus.

An information form was provided to all potential participants and if they agreed and were suitable for participation a consent form was completed by all. A basic questionnaire was used to obtain necessary information from the participants for the purposes of the study concerning the subject's general health and use of any medications that may relate to ocular or other systemic conditions that might influence or impact the results.

Procedure

The participants were placed in a room with normal lighting (400 lux) for about 30 min to adapt to the light conditions. Firstly, 40 successive measurements were taken on the right eye of each participant with a brightly illuminated target as it is normally set in the auto-refractor (LL). Secondly, the illumination of the target in the auto-refractor was reduced by means of placing a dark-filtered spectacle lens of power 0.0 D (10% transmission) in front of the right eye of each participant. Thereafter, another 40 measurements were then taken on the right eye of each participant. The measurements were taken in batches of five with intervals of 5 s to avoid fatigue. Subsequently, the lighting in the room was turned off and participants were left in the dark for about 30 min so that they become dark-adapted. The same procedures as before were repeated under the same conditions except that the lighting was switched off. Therefore, in total, 160 measurements were obtained per participant under the four conditions. All measurements were taken by the same person. The measurements were taken over a period of five days.

Statistical analysis

The data were analysed using Matlab® together with software developed by Harris, Malan and Rubin.[17] Multivariate methods were used to analyse the data. Each power was converted into a dioptric power matrix **F**, which was then converted into scalar $F_I\mathbf{I}$, ortho antistigmatic $F_J\mathbf{J}$ and oblique antistigmatic $F_K\mathbf{K}$ components. Scatter plots of the data for each participant under different testing conditions were plotted in symmetric dioptric power space (SDPS) and then analysed. This method of analysis is similar to that of Thibos et al.[18] that uses vector $\boldsymbol{t} = (M\ J_0\ J_{45})^T$ to perform similar analyses but generally without stereo-pair scatter plots.

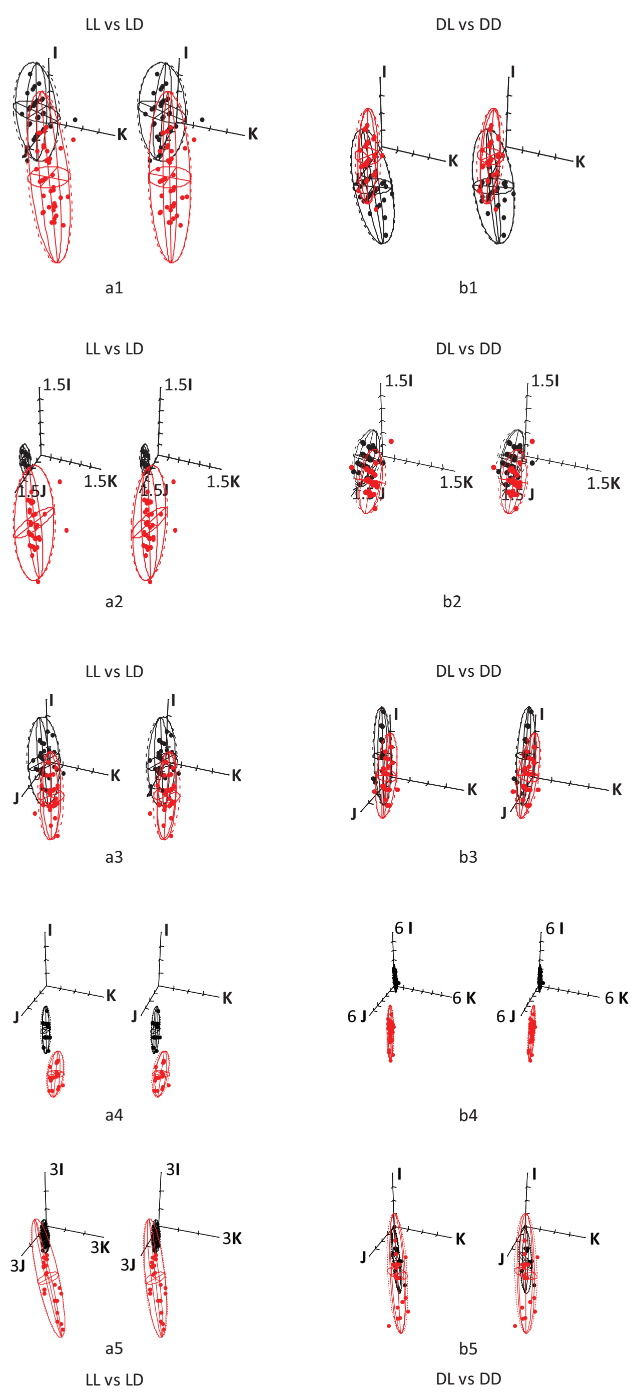
Ethical considerations

Ethical clearance to conduct this study was obtained from University of Johannesburg, Faculty of Health Sciences Research Ethics Committee (REC-1000-2021). Participation was voluntary and informed consent from each participant was obtained. All investigations and measurements performed in this study adhered to the Declaration of Helsinki.

Results

The results are shown in Figure 1 by means of stereo-pair scatter plots shown together with the estimated ellipsoidal surfaces of constant probability density containing an estimated 95% of the population.[19,20,21,22] Each dot on the scatter plots represents one measurement, and the origin of the graphs are at $(0\ 0\ 0)^T$ D, that is, the state of emmetropia. The abbreviations, LL, LD, DL and DD refer to the lighting and target conditions, light-light, light-dark, dark-light and dark-dark conditions, respectively. The ellipsoids and other estimates were calculated under the assumption of data normality.

Table 1 shows the mean refractive states for the right eyes of each of the five participants in the matrix notation and conventional clinical form (sphere, cylinder and axis). The variance–covariances are based on F_I, F_J and F_K. There are six distinct entries in each matrix that describes three variances



Note: The origins of the graphs are all at $(0\ 0\ 0)^T$ D or emmetropia and each data point in the space represents one autorefractive measurement. Figures a1 and b1 through to a3 and b3 are for participants 1 to 3 and each tick interval represents 0.25 D while for a4 and b4 and a5 and b5 are for participants 4 and 5. Each tick interval represents 1.0 D. The black and red ellipsoids for a1 through to a5 represent light room light target and light room dark target measurements, respectively, while the black and red ellipsoids in b1 through to b5 represent dark room and a light target and dark room and dark target, respectively.

LL, light room light target; LD, light room dark target; DL, dark room and a light target; DD, dark room and dark target; D, dioptre; I, stigmatic component; J, ortho antistigmatic component; K, oblique antistigmatic component.

FIGURE 1: Stereo-pair scatter plots of autorefraction measurements for the right eyes with estimated surfaces of constant probability density containing 95% of the population for each participant.

and three covariances of the sample concerned. The diagonal entries S_{11}, S_{22} and S_{33} show the variances for F_I, F_J and F_K, respectively. The off-diagonal entries $S_{12} = S_{21}$, $S_{13} = S_{31}$ and $S_{23} = S_{32}$ show the covariances between F_I and F_J, F_I and F_K and F_J and F_K, respectively.

Figure 2 includes 95% confidence ellipsoids on the sample means (CESM) for all participants for all conditions. The origin of the graphs are at $(0\ 0\ 0)^T$ D. Confidence ellipsoids describe the distribution of the populations (of means) for the dioptric power measurements for the five participants. The confidence ellipsoids are confidence regions centred on the sample means (or centroids).[15,16,23,24] They also provide an estimation of the mean of the population. Therefore, for example, one can assume at a 95% level of confidence that the mean of a particular population of dioptric power measurements will lie within the respective 95% confidence ellipsoid. Confidence ellipsoids also demonstrate the accuracy of the mean, that is, the smaller the 95% confidence ellipsoid, the more confident one can be about the accuracy of the mean. If the confidence ellipsoids of two samples being compared do not intersect, then one can argue that at a confidence level of 95% a difference in means is present.[17,25] The opposite applies when the confidence ellipsoids intersect. However, formal hypothesis tests[15,17,23,25] are used to compare the variances and also means for any two samples concerned (one can also compare multiple means, say, four, simultaneously).

Hypothesis tests

Hypothesis tests were conducted on the paired (two samples) variance-covariances and paired (two samples) means for the autorefraction data collected. For example, the equality of variance-covariances (or means) for LL against the variance-covariances (or means) for LD can be compared (see the first row for Participant 1 in Table 2).[15,18,23,25] Variances and covariances for the two samples are first tested and only where equality of variances and covariances are found, one proceeds to test the sample means for equality. Mostly, in Table 2, unequal variances and covariances were found and therefore tests on the means were not used except for Participants 2 and 3.

Discussion

Table 1, Figure 1 and Figure 2 suggests that as we change from a bright room and bright target (LL) to LD, the eye's refractive state of all participants experienced a myopic shift. The largest significant difference in the variance-covariances and the means was found with Participant 5 whose myopic shift was approximately 2.40 D. The smallest myopic shift for Participant 3 was approximately 0.50 D. Reasons for the myopic shift could be that the participants were accommodating during autorefraction because they perhaps had difficulty focusing in dark conditions. The myopic shift for the other participants (1, 2 and 4) was approximately the same and varied between 1.0 D and 1.50 D. All myopic shifts appeared to be mainly spherical or stigmatic (see Table 1).

For the DL-DD conditions all participants, except for Participant 1, also underwent myopic shifts. Participant 1 experienced an ≈0.50 D hyperopic shift. The highest myopic shift was for Participant 4 who experienced a 4 D shift. The other participants (2, 3 and 5) experienced about 0.50 D

TABLE 1: Statistics of scientific means, clinical means ($S\ C\ A = F_s\ F_c\ A$) and variance-covariances (in row vector format $(S_{11}\ S_{22}\ S_{33}\ S_{21}\ S_{31}\ S_{32})^T$ D^2) for the refractive behaviour of the right eye of each participant under photopic and scotopic lighting conditions for two different target brightness.

Participants	Scientific means	Clinical means ($S\ C\ A$) = ($Fs\ Fc\ A$)	Variance-covariances $(S_{11}\ S_{22}\ S_{33}\ S_{21}\ S_{31}\ S_{32})^T$ D^2
Participant 1			
LL	0.10**I** - 0.04**J** - 0.23**K**	0.33 - 0.47 × 130	$(0.072\ 0.007\ 0.019\ 0.001\ 0.001\ 0.004)^T$
LD	-0.92**I** - 0.08**J** - 0.09**K**	-0.79 - 0.25 × 114	$(0.229\ 0.010\ 0.013\ 0.005\ -0.011\ -0.000)^T$
DL	-0.59**I** + 0.01**J** - 0.17**K**	-0.42 - 0.34 × 136	$(0.086\ 0.005\ 0.013\ 0.004\ -0.010\ 0.000)^T$
DD	-0.18**I** - 0.00**J** - 0.23**K**	0.06 - 0.47 × 134	$(0.061\ 0.004\ 0.050\ 0.000\ 0.002\ 0.000)^T$
Participant 2			
LL	0.17**I** + 0.54**J** - 0.17**K**	0.74 –1.13 × 171	$(0.014\ 0.005\ 0.001\ 0.001\ -0.001\ -0.001)^T$
LD	-1.26**I** + 0.43**J** - 0.04**K**	-0.84 - 0.85 × 177	$(0.197\ 0.051\ 0.012\ 0.006\ -0.008\ -0.016)^T$
DL	0.22**I** + 0.50**J** - 0.11**K**	0.73 - 1.02 × 174	$(0.025\ 0.021\ 0.012\ -0.011\ 0.003\ 0.003)^T$
DD	-0.31**I** + 0.40**J** - 0.09**K**	0.10 - 0.83 × 173	$(0.037\ 0.025\ 0.008\ -0.010\ -0.001\ -0.001)^T$
Participant 3			
LL	0.03**I** + 0.05**J** - 0.05**K**	0.10 -0.14 × 155	$(0.063\ 0.009\ 0.005\ 0.001\ -0.003\ -0.003)^T$
LD	-0.49**I** + 0.06**J** + 0.05**K**	-0.41 -0.16 × 20	$(0.061\ 0.005\ 0.005\ -0.001\ 0.001\ 0.000)^T$
DL	0.38**I** + 0.09**J** - 0.08**K**	0.49 - 0.23 × 158	$(0.077\ 0.002\ 0.002\ -0.002\ 0.001\ 0.000)^T$
DD	0.063**I** + 0.07**J** - 0.05**K**	0.15 - 0.17 × 163	$(0.054\ 0.005\ 0.003\ -0.005\ 0.004\ 0.001)^T$
Participant 4			
LL	-0.750**I** + 0.110**J** + 0.005**K**	-0.64 - 0.22 × 1	$(0.022\ 0.003\ 0.001\ -0.002\ -0.000\ 0.000)^T$
LD	-1.60**I** + 0.015**J** + 0.100**K**	-1.50 - 0.20 × 41	$(0.021\ 0.003\ 0.002\ -0.023\ 0.001\ -0.001)^T$
DL	0.788**I** - 0.150**J** + 0.016**K**	0.94 - 0.30 × 87	$(0.320\ 0.010\ 0.003\ 0.015\ -0.002\ -0.000)^T$
DD	-4.959**I** + 0.485**J** - 0.406**K**	-4.33 - 1.27 × 160	$(1.178\ 0.018\ 0.013\ -0.016\ 0.031\ -0.004)^T$
Participant 5			
LL	-0.613**I** - 0.070**J** - 0.148**K**	-0.45 -0.33 × 122	$(0.102\ 0.016\ 0.005\ -0.005\ -0.006\ -0.001)^T$
LD	-3.051**I** - 0.267**J** - 0.147**K**	-2.75 -0.61 × 104	$(1.684\ 0.096\ 0.031\ 0.326\ -0.112\ -0.034)^T$
DL	-0.580**I** + 0.0616**J** + 0.043**K**	-0.51 -0.15 × 18	$(0.047\ 0.007\ 0.004\ 0.001\ -0.001\ 0.005)^T$
DD	-0.800**I** + 0.092**J** + 0.068**K**	-0.69 -0.23 × 18	$(0.133\ 0.009\ 0.007\ -0.017\ -0.009\ -0.006)^T$

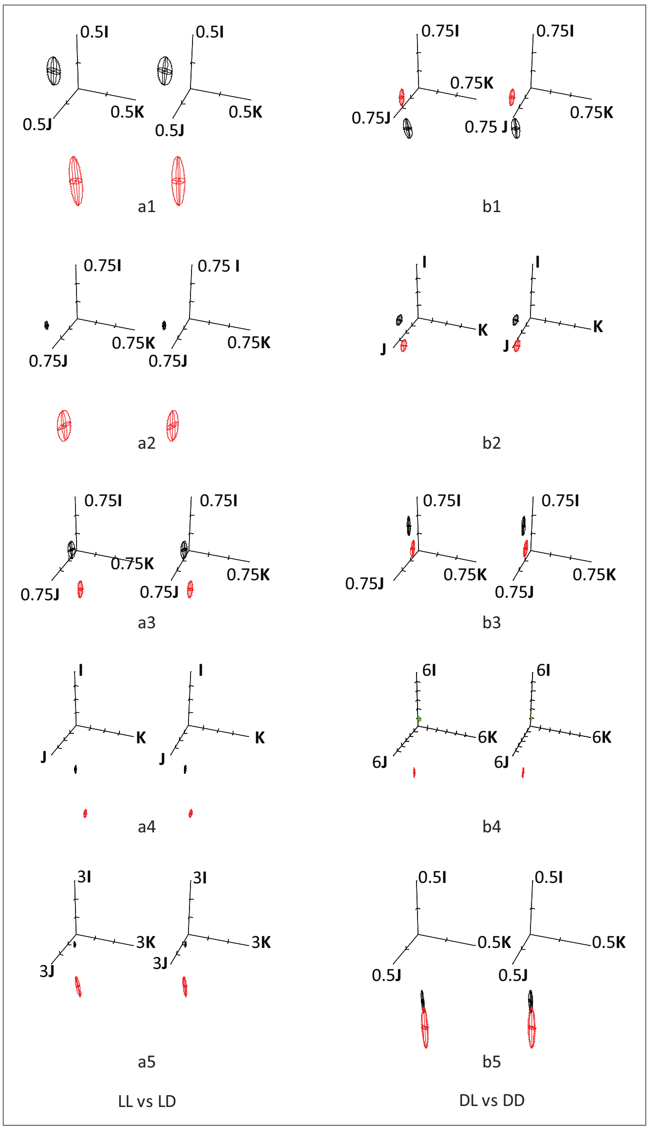
LL, light room light target; LD, light room dark target; DL, dark room and a light target; DD, dark room and dark target.

myopic shift. Once again, all refractive changes appeared to be stigmatic. The possible causes of the shifts could be related to the fact that the target might have not been clear through the filter used or relating to over-accommodation for the target (that was not clear).

The hypothesis tests (Table 2) suggested that there were significant differences at the 95% level in the variances and covariances for most participants. However, this was not the case for Participant 2 (DL-DD) and Participant 3 (LL-LD), where the means were unequal. The results show that the greatest myopic shift occurs under bright lighting conditions viewing a dark target. Participants 1, 2, 4 and 5 show that they became more myopic when they changed from light conditions with a light target to light room conditions with a dark target. (cylinder changes do not appear to be significant clinically as they are mostly > 0.25 D and the axis changes are only a few degrees.) Vision and refractive behaviour seem to be dependent on illumination. Ambient lighting has effects on the pupillary diameter of individuals, thus leading to changes in the ocular refractive state. From the results obtained, it is evident that when we change the ambient light conditions there appears to be smaller or larger differences in the refractive state of the eye. One of the reasons attributed to this is changes in pupil diameter under different lighting conditions.

Norton and Siegwart[22,26] reviewed light levels, refractive development, and myopia. They reported that outdoor activities protect the eye from becoming myopic; this may be so because the illumination level outdoors is high.[22,26] From our study, all participants' accommodation was relaxed, and refractive states of eyes were less myopic or rather hyperopic when they were in a light room with a light target (LL); this is consistent with other studies.[22,23,26,27] Support provided by Norton and Siegwart states that dark or low levels of light result in eyes being more myopic if only axial elongation with no corneal changes occurs.[22,26] This might have been the case with four of the participants whose eyes became more myopic as we moved from light to dark conditions.

Dark focus of accommodation refers to the refractive power of the eye in the absence of an external stimulus for accommodation, as is the case, for example, in total darkness. Research has shown that as illumination is decreased, accommodation shifts from a focus that is more or less appropriate to the actual distance of the stimulus to an intermediate dark focus.[25,28] Shifts towards the dark focus point also occur when the subject looks through a small artificial pupil, thereby increasing the depth of field and rendering accommodation unnecessary as well as when the subject is looking into a bright field containing no contours or texture, namely a *Ganzfeld*.[26,29] A *Ganzfeld,* is an absolutely homogeneous region of space covering the whole visual field of an observer. It can be of any single uniform wavelength and intensity. It was first introduced in 1930 by a German psychologist Wolfgang Metzger (1899–1979). The interest was in elementary visual phenomena produced by poor visual conditions. The *Ganzfeld* contains no luminance border, luminance ramp, or texture. The light reaching the eye is absolutely equal in all possible directions. Such conditions can occur naturally during



Note: The origin of the graphs are at $(0\ 0\ 0)^T$ D. For Figures a1 and b1 through to a3 and b3 each tick interval represents 0.25 D while for a4 and b4 and a5 and b5 each tick interval represents 1 D. The black and red ellipsoids for a1 through to a5 represents light room light target and light room dark target measurements, respectively, while the black and red ellipsoids in b1, b2, b3 and b5 represent dark room and a light target and dark room and dark target, respectively. For b4 dark room and a light target is represented by green.

LL, light room light target; LD, light room dark target; DL, dark room and a light target; DD, dark room and dark target; D, dioptre; I, stigmatic component; J, ortho antistigmatic component; K, oblique antistigmatic component.

FIGURE 2: Confidence ellipsoids (95%) on the means for the right eyes of all participants.

a snowstorm or in an airplane flying through clouds. Persons of normal sight will experience a uniform grey fog on indeterminate depth. This occurs regardless of the physical intensity and wavelength of the *Ganzfeld*.[24,28]

It appears that whenever the visual field becomes impoverished in terms of specific stimuli for accommodation, or when accommodation has no influence on the quality of the retinal image, the accommodation response shifts towards the dark focus. Leibowitz and Owens (cited by Miller), examined a sample of 124 college-age subjects and reported that the mean dark focus was 1.71 ± 0.72 D (corresponding to a focal distance of 58.5 cm).[27,29] There were individual differences, ranging from 0 D to 4 D. Thus,

TABLE 2: Hypothesis testing on the variance-covariances and means for five participants under the different ambient and target conditions.

Participants	Conditions	Test statistics (u or w)	Critical values (χ^2 or F)	Results
1	LL-LD	17.77	12.59	Reject H_0†
	DL-DD	13.20	12.59	Reject H_0
2	LL-DL	130.10	12.59	Reject H_0
	DL-DD	9.16	12.59	Do not reject H_0‡
		405.18	2.61	Reject H_0§
3	LL-LD	9.44	12.59	Do not reject H_0
		41.23	2.61	Reject H_0¶
	DL-DD	17.27	12.59	Reject H_0
4	LL-LD	22.03	12.59	Reject H_0
	DL-DD	38.02	12.59	Reject H_0
5	LL-LD	91.9318	12.59	Reject H_0
	DL-DD	51.96	12.59	Reject H_0

Note: For the variance-covariances, the test value (u) is compared with the critical value (χ^2 = 12.59) and if u is greater than 12.59, then the null hypothesis (H_0) of equality of variances and covariances is rejected. For means, the test value (w) is compared with the critical value (F = 2.61) and if w is greater than 2.61, then the null hypothesis of equality is rejected and there is a significant difference between the two means under comparison.

LL, light room light target; LD, light room dark target; DL, dark room and a light target; DD, dark room and dark target.

†, Unequal variances and covariances; ‡, equal variances and covariances; §, means unequal; ¶, means unequal.

everyone appears to have a characteristic dark focus. This dark focus serves as a reference point for the accommodation response in the absence of clear visual information for accommodation or when accommodation is unnecessary for a clear image. Indeed, some research indicates that the dark focus response influences accommodation in the viewing of even highly contoured, well-illuminated stimuli, producing a certain degree of over-accommodation for far objects and under-accommodation for near objects.[27] Dark focus apparently also accounts to a considerable degree for various anomalous myopias, including night myopia,[28,30] empty field or *Ganzfeld* myopia,[26,31] and instrument myopia and for the paradoxical variation of VA with viewing distance.[29,32]

Grossmann et al.,[30,33] conducted research whereby the aim was to investigate the influence of an imaginary target at finite distances on the state of accommodation at scotopic luminance. They measured accommodation using an open-field WAM 5500, GRAND SEIKO auto-refractor. Full corrected right eyes of 39 subjects ranging from 18 years to 40 years were investigated. Accommodation measurements in photopic luminance were taken for 6 m of empty field and for optotype fixation at 2 m, 1 m and 0.5 m, respectively. At scotopic luminance, the dark focus of accommodation was examined directly after darkening and after 10 min of dark adaptation. After adaptation, subjects had to visualise imaginary targets in the four distances while accommodation was measured. As a result, there was no significant change in dark focus after dark adaptation (–0.26 ± 0.52 D).

Possible limitations of the study

A larger sample (> 5) of participants may have provided different results. Some eye fatigue during repeated autorefraction measurements may have had unknown influences and cycloplegia was not used to paralyse ocular accommodation. Autorefraction through the filtered lens may have affected the measurements to some extent and possibly caused some blurring of the target within the instrument that might have also affected accommodation.

Conclusion

Previous studies have suggested that changes in ocular accommodation at decreasing luminance levels are insignificant when measured by using an open-field autorefractor compared with other studies. However, this study did not use an open-field autorefractor, thus it extends knowledge as to possible effects of ambient environmental and target luminance upon non-cycloplegic intraocular autorefraction in closed-field environments.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

T.I.M. contributed towards the conceptualisation of the research project, guided on the methodology, and assisted in the drafting and reviewing of the original project. A.C. supervised the students and contributed towards the conceptualisation of the research project, and methodology analysis of the data.

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Data availability

Data supporting the findings of this study are available from the corresponding author, T.I.M., on request.

Disclaimer

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