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Research Article

# The Effect of Sustained Eye Rotation Upon Central and Peripheral Refraction in Young, Adult Myopic Subjects

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## Abstract

**Aim:** To determine whether ocular movement can affect the shape of the globe and lead to measurable refractive change as the rigidity of myopic eyes are lower than emmetropic and hyperopic eyes.

**Methods:** Twenty three healthy subjects aged 18 to 30 years old participated in the experiment, and all mean spherical equivalent of refraction (MSE) was ≤ -1.00DS with central cylindrical refraction < -1.25 DC. One drop of tropicamide hydrochloride 1% was instilled 20 minutes prior to measurement to induce mydriasis and mild cycloplegia. Central and peripheral refraction (20 degrees temporal retina) was measured using a hand held infrared auto-refractor (Grand Seiko FR-5000) with a minimum of ten static measurements being averaged to give the MSE at each location.

**Results:** There was no significant variation in central and temporal MSE with ocular rotation, even after 10 minutes of off-axis fixation. Considerable inter-subject variation was observed in this effect. Ten minutes of eye rotation caused a further increase in myopia at the temporal location in a sub-group.

**Conclusion:** The action of the extraocular muscles on the globe has a measurable effect upon the retinal shape assessed by off-axis refraction in myopic subjects, although it is not statistically significant. The effect appears to be restricted to peripheral retinal locations. The effect of the extraocular muscles upon retinal shape shows considerable inter-subject variability, which requires further investigation.

**Keywords:** Eye Rotation; Eye Shape; Central Refraction; Peripheral Refraction; Myopia; Shin-Nippon Autorefractor

## Introduction

Previous work showed a relationship between the refractive profile of the peripheral retina and the central refractive error in human eyes, where longer eyes with myopic central refractive error tended to be relatively hyperopic in the periphery. Conversely, shorter eyes with central hyperopic refractive error tended towards relative peripheral myopia [1-7].

In addition, animal models have demonstrated that localised and/or peripheral retinal defocus can influence refractive development even when the central macular area is absent [6,8-13].

The potential link between myopia development and relative peripheral hyperopia has directed interest towards investigating off axis refraction. The relation between ocular shape and refractive error was evaluated in the right eye of 822 children aged between 5 and 14 years old [3]. They measured refractive errors centrally and 30° temporally using the Canon R-1 auto refractometer (Canon, Lake Success, NY) and axial ocular dimensions by A-scan ultrasound (Model 820, Humphrey Instruments, San Leandro, CA). The authors reported that myopic subjects had relative peripheral hyperopia (+0.80 ± 1.29D) suggesting a prolate eyeball. Furthermore, relative myopia in the periphery was found in emmetropes (-0.41 ± 0.75D) and hyperopes (-1.09 ± 1.02D) indicating an oblate eyeball shape [3].

Peripheral astigmatism in the horizontal meridian was measured up to 60° temporally and nasally in 10° steps, using Topcon auto-refractometer (model III, Topcon Inc, Tokyo, Japan) in a group of thirty one healthy subjects divided into 3 groups: 15 myopes (MSE ranged between -1.00D and -7.87D), 6 emmetropes (MSE ranged between -0.80D and +0.74D) and 10 hyperopes (MSE ranged between +0.75D and +4.50D) [14]. The instrument was specially modified using a periscopic system to enable off-axis targets to be presented along the horizontal meridian. He found asymmetry between nasal and temporal retina, in which astigmatism was significantly larger on the temporal side beyond 30 degrees ($p < 0.05$). Furthermore, the results showed a progressive increase in the amount of astigmatism off-axis in 91% of the subjects [14].

Another study measured the peripheral refraction in young healthy adults using two methods: automated eccentric infrared photo-refractor, and double pass aberrometry [5]. In the first method, an automated eccentric infrared photo-refractor was used to examine thirty one subjects: 8 emmetropes (MSE = -0.17 ± 0.49D), 18 myopes (MSE = -3.06 ± 1.62D) and 5 hyperopes (MSE = +4.50 ± 2.21D). Participants were instructed to maintain head orientation straight with eccentric fixation up to 22° temporally. They found that all subjects were myopic in the periphery. However, hyperopic subjects had relatively more peripheral myopia (-1.24 ± 1.08D; $p < 0.05$) compared to myopic subjects (-0.04 ± 1.38D), while differences from emmetropic subjects were not significant [5].

In the second method, a double pass aberrometer was used to examine twenty five subjects: 11 emmetropes (MSE = -0.11 ± 0.35D), 9 myopes (MSE = -4.75 ± 1.90D), and 5 hyperopes (MSE = +2.42 ± 1.16D). With eyes rotated up to 45° temporally in the horizontal meridian and head positioned straight ahead, the authors found that while MSE in the peripheral retina was myopic for all three groups, hyperopes (-6.69 ± 2.29D), emmetropes (-2.85 ± 1.72D), myopes (-0.12 ± 2.27D), the levels of peripheral myopia were significantly different between them ($p < 0.05$) [5].

It has been found that the muscle force required to rotate the eyeball to the nasal direction is greater than that when rotation of the eyeball is in the temporal direction, which means the medial rectus is a stronger muscle than lateral rectus [15]. The average of force generated by the medial rectus was 74.83g (ranged between 48 and 103g), while the average of force generated by the lateral rectus was 59.14g (ranged between 45 and 92g). This indicated that the mean value of muscle force of active medial rectus was 25% greater than the muscle force of lateral rectus [15].

Two experiments were conducted in 2007 to study the effect of non-horizontal viewing and reading on axial refractive error [16]. The first experiment included twenty healthy adults divided into two groups (10 emmetropes and 10 myopes). The mean age for the emmetropic group was 23.9 ± 5.20 years old, with refractive error ranged between plano and +0.67D (mean ± SD = +0.10 ± 0.22D), whereas the mean age for the myopic group was 23.50 ± 6.00 years old and refractive error ranged between -1.25 and -7.25D (mean ± SD = -3.44 ± 2.27D). They measured refraction using a Hartmann-Shack aberrometer (IRX3, Imagine Eyes, Paris, France). Ten measurements of axial refraction were taken while the head was maintained in a straight ahead position, and the right eye rotated to fixate either rightward or leftward by 30° with the left eye being occluded. They found a significant difference in axial MSE between central fixation and temporal fixation ($p < 0.05$). On the contrary, there was no significant difference in axial MSE between the central fixation and 30° nasal fixation ($p > 0.05$) [16].

The second experiment included ten healthy subjects (4 emmetropes and 6 myopes), with mean age of 22.3 ± 3.60 years old. The MSE for emmetropes was +0.14 ± 0.35D (ranged between plano and+0.67D), and MSE for myopes was -3.25 ± 2.33D (ranged between -1.25 and -7.75D). The measurement technique and instrument were as same as the first experiment. After taking the baseline measurements, the left eye occluder was removed and the subjects were allowed to wear their normal distance correction. The participants were asked to read a piece of text binocularly at 25 cm for 20 minutes. Then, refractive error was measured again (3 readings per measurement). No significant change in refractive error was noted due to the task ($p > 0.05$) [16].

In a subsequent study, the same authors investigated whether the force generated by the extraocular muscles could distort eye shape and affect refractive error across the horizontal visual field [17]. The peripheral refraction of the right eye was measured in ten healthy adult subjects (6 myopes and 4 emmetropes). The mean age was 22.3 ± 3.6 years old. The MSE for emmetropic subjects was +0.16 ± 0.31D (ranged between plano and +0.62D), and the MSE for myopic subjects was -3.42 ± 2.40D (ranged between -1.25D and -7.75D). Refractive error was measured in two conditions. Firstly, by turning the eyes horizontally to fixate on several targets placed in front of the subjects starting from 0˚ up to 30˚ in 5˚ intervals, and secondly, by turning the head to view the same targets while keeping the eye in primary gaze. The duration of fixation at each position was approximately 1 minute. The open field Shin Nippon SRW-5000, infrared auto-refractor (Grand Seiko, Tokyo, Japan) was used to measure peripheral refraction using an average of 3 readings taken at each position. They found no significant difference in peripheral refractive error between the two conditions [17]. The same experimental procedure was repeated on another five subjects (MSE = -0.23 ± 1.09D; mean age = 29.8 ± 6.4years) with an extended fixation time of 2.50 minutes. However, the increased time of rotation had no significant effect on the peripheral refractive status of the eye [17].

Since the duration of off axis fixation for 2.50 minutes had been tested previously without significant effect, we decided to extend the time to 10 minutes based on the findings of Alhazmi and associates [18] as we believe it is manageable.

## Aim of the Study

The aim of this study was to determine whether the force generated by the extraocular muscles during prolonged ocular rotation of 20˚ off axis along the horizontal meridian will affect the shape of the globe and in turn alter the refractive status of the peripheral retina.

## Methods

### Subjects

Twenty three healthy, visually normal, myopic adults (12 males and 11 females) were recruited from the student population in Glasgow Caledonian University. The age of the participants ranged between 18 and 30 years old (mean ± SD = 23.82 ± 3.53 years). The MSE of the group ranged between -1.25D and -10.50D (mean ± SD = -3.39 ± 2.89D) with all subjects had astigmatism of no less than -1.25DC. All subjects had corrected visual acuity of 6/6 or better in both eyes. One drop of tropicamide hydrochloride 1% was instilled in the right eye of each subject 30 minutes prior to the experiment to induce mydriasis, with a further drop installed 20 minutes later if the pupil diameter was less than 5 mm. The left eye was occluded during the experiment.

The experiment was approved by the School of Health and Life Sciences Ethics Committee at Glasgow Caledonian University and was conducted in accordance with the Declaration of Helsinki for research involving human subjects. All participants completed a consent form and were given information leaflets, after verbal explanation about the nature of the study and any possible consequences.

### Instrumentation

Refractive error was measured using Grand Seiko FR-5000 autorefractometer (Ajinomoto Trading Inc., Tokyo, Japan). This instrument has been found to be accurate and reliable in terms of refraction measurement [19,20]. To meet the requirements of our experiment, the instrument was mounted on a rotating platform to allow rotation temporally and nasally around the eye.

### Fixation targets

Fixation targets (1 and 2) were presented with an angle of 20˚ between them, located at 1m in front of the subject. The targets were positioned such that one target was directly in front of the right eye while the other target was 20˚ temporal to the visual axis.

### Experimental procedure

Ten measurements of central (0˚) and peripheral (20˚ temporal) refractive error were obtained from the right eye of all subjects in the experimental paradigm described below. 10 measures of sphero-cylindrical refractive error were recorded by the instrument and converted into mean spherical equivalent.

Measurements were obtained in four eye positions as described below:

1. Baseline measurements were obtained in the central and peripheral locations with the subject fixating upon the central target with no eye rotation.
2. The subject then rotated their eye to fixate on the peripheral target placed at 20˚ temporally and the measurements were

repeated, rotating the auto-refractor as necessary to obtain the measurements.

3. The subject was then asked to maintain fixation on the peripheral target with the eye rotated for 10 minutes. Measurements were repeated while the subject continued fixating on the peripheral target.
4. Finally, the subject then returned to fixate on the central target and measurements of central and peripheral refraction were repeated at this position.

At all times the head was stationary and fixation of each target was achieved by eye rotation only. The duration of measurement for each position was no more than 1 minute, with a further minute allowed for adjustment of eye position (Figure 1 and 2). An average of 10 readings was calculated for every measurement point. Individual measurements were then converted to MSE after ensuring that no individual reading had astigmatism less than -1.25DC [21].

### Data analysis

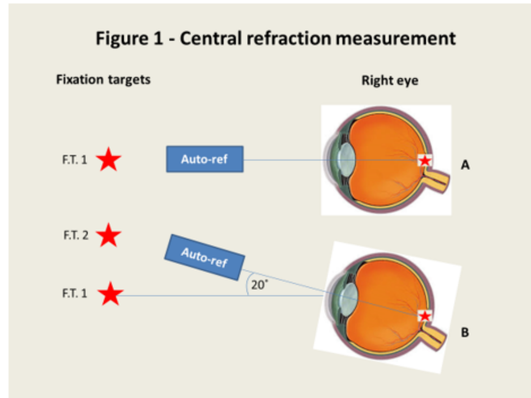
SPSS software version 22 for Windows (SPSS Inc., Chicago, IL, USA) was used to perform statistical analysis for our data (www.ibm.com/software/analytics/spss/).

A Shapiro-Wilk test was performed to determine the normality. A two-way repeated measures ANOVA was used to analyse the data, with time as the repeat measure and retinal location as a factor. Results were considered statistically significant if the p value is < 0.05.

## Results

Central MSE (prior to any eye rotation) was considered as baseline values and varied from -1.25 to -10.50 D, while temporal MSE (prior to any eye rotation) varied from -1.25 to -8.91 D. Table 1 displays the summary of MSE for central and temporal refraction in all positions before and after temporal fixation. Values show mean ± SD.

A two-way repeated measures ANOVA shows no significant variation over time in central or temporal refraction ($F = 0.512$; $df = 3,20$; $p = 0.679$). There was no significant variation between central and temporal refraction values at any of the time points ($F < 0.0001$; $df = 1,22$; $p = 0.985$). There was no significant interaction between these factors ($F = 1.094$; $df = 3,20$; $p = 0.375$).



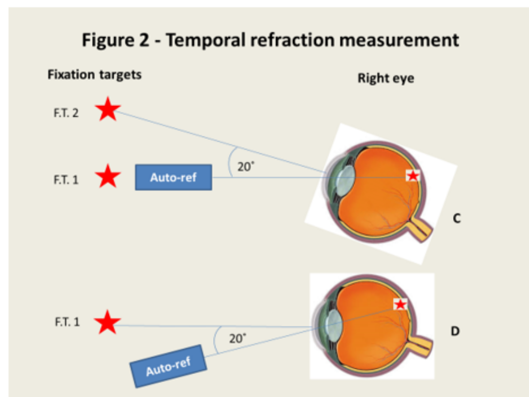




**Figure 1 and 2:** Demonstrate the infrared beam entering the right eye at 0˚ to measure the central refraction (A), how both the eye and the instrument were rotated 20˚ temporally in order to measure the central refraction again (B), eye rotation 20˚ temporally with the infrared beam entering the right eye at 0˚ to measure the peripheral refraction (C) and how the instrument was rotated 20˚ nasally in order to measure the peripheral refraction again (D). It can be seen that both beams entered the eye through the central curvature of the cornea and passed close to the nodal point.

At the beginning of the experiment, the baseline central refraction was greater than the baseline temporal refraction; however, the difference was not statistically significant. It can be seen that there was considerable inter subjective variation although a substantial number of subjects whose axial myopia is low actually showed relative peripheral myopia (Figure 3).

| Position | Before temporal fixation | | | After temporal fixation | | |
|---|---|---|---|---|---|---|
| | No rotation (mean ± SD) | Rotation (mean ± SD) | P value | No rotation (mean ± SD) | Rotation (mean ± SD) | P value |
| Central Rx (D) | -4.25 ± 2.70 | -4.24 ± 2.49 | > 0.05 | -4.31 ± 2.73 | -4.21 ± 2.60 | > 0.05 |
| Temporal Rx (D) | -4.08 ± 2.13 | -4.09 ± 2.41 | > 0.05 | -4.21 ± 2.28 | -4.24 ± 2.43 | > 0.05 |
| Central vs Temporal | | | > 0.05 | | | > 0.05 |

**Table 1:** Displays the summary of MSE for central and temporal refraction in all positions before and after temporal fixation. Values show mean ± SD.

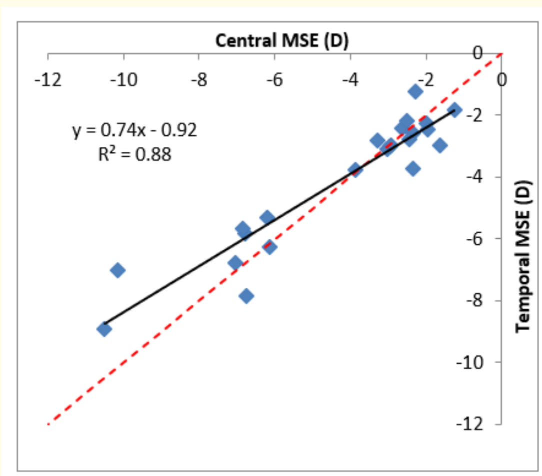



**Figure 3:** Shows the relationship between central and peripheral MSE with no eye rotation and no temporal fixation.

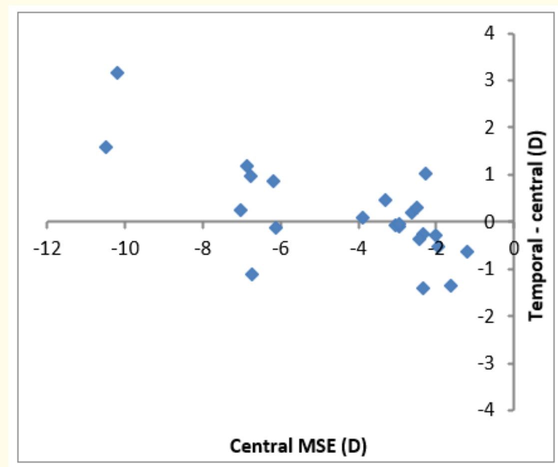



**Figure 4:** Shows the peripheral refraction in low and high myopia and how it became more hyperopic as myopia increased. In this figure, the difference between central and temporal MSE at the beginning of the experiment (no rotation) is plotted against the central MSE baseline measurements.

The peripheral refraction among the myopic subject group tended to show relative hyperopia as the central myopia increased. Although relative peripheral hyperopia (RPH) exists in ~50% of the subjects, the absolute MSE at the 20 degree temporal point is myopic in all subjects (Figure 4).

There was no significant difference between central (group MSE = -4.31 ± 2.73D) and temporal (group MSE = -4.21 ± 2.28D) refraction after 10 minutes of temporal fixation (Figure 5).

The effect of eye rotation upon central MSE was variable after 10 minutes of off-axis fixation, as can be seen in figure 6.

The effect of ocular rotation upon the MSE measured at 20° in the temporal retina was also variable, although there is a tendency for ocular rotation to cause an increase in myopia at this point in the subjects who were more myopic (Figure 7).

## Discussion

The present study did not reveal clear patterns of change in peripheral refraction due to eye rotation for the myopic subjects. Although, we found measurable differences in individual subjects, there was considerable variation in the effect of rotation within

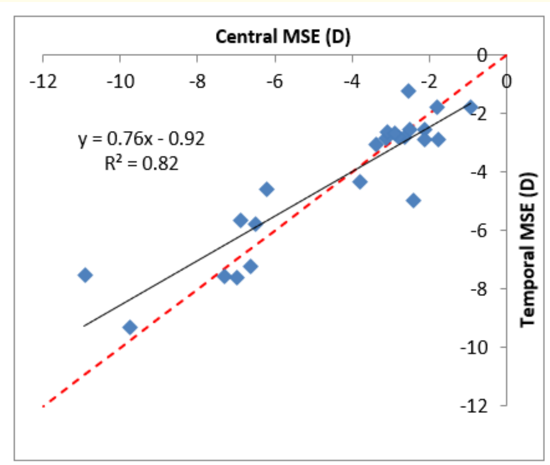



**Figure 5:** Shows the relationship between central and peripheral MSE following 10 minutes of temporal fixation.

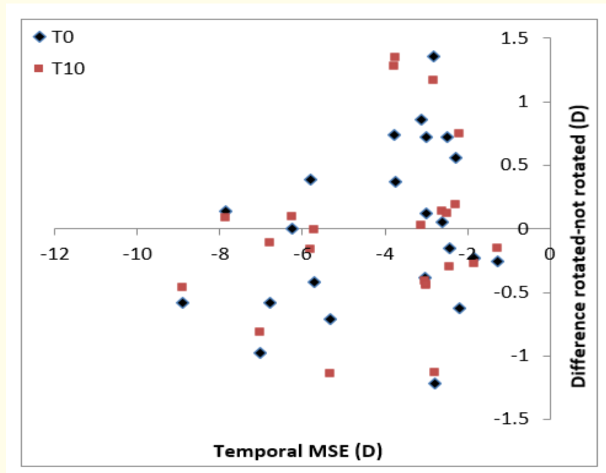



**Figure 7:** Shows the difference between rotated and non-rotated measurement of temporal MSE before and after 10 minutes of off-axis fixation against the baseline temporal MSE.

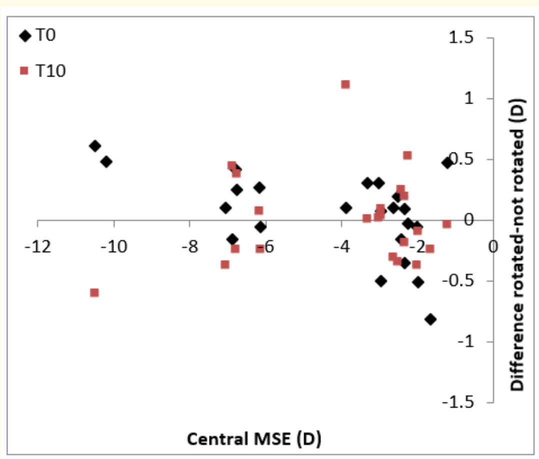



**Figure 6:** Shows the difference between rotated and non -rotated measurement of central MSE before and after 10 minutes of off-axis fixation against the baseline central MSE.

the group. It is worth mentioning that relative peripheral refraction was both myopic and hyperopic in the myopic subject group, where only ~50% of the participants exhibited relative peripheral hyperopia.

Several previous reports have investigated retinal profile, either by keeping the eye fixed and rotating the instrument, or by keeping the instrument fixed and rotating the eye [3,5,14,16,17,22].

A number of studies have reported that myopic subjects are likely to have relative peripheral hyperopia, whereas hyperopic subjects have relative peripheral myopia [3,4,5,14,23]. However, the absolute values of the peripheral refractive error are often not reported in these studies making it difficult to judge whether this relationship holds across the range of ametropia in the population or not.

The aim of the present work was to investigate whether the force generated by the extraocular muscles during eye rotation had any measurable effect upon the refractive status of the central or peripheral retina in subjects with varying degrees of myopia. This is the first study we are aware of, to examine the effect of prolonged eye rotation (duration of 10 minutes) on peripheral refraction in subjects with myopia. In terms of typical visual tasks, this is more than what had been applied in previous studies.

The findings of the current study suggest that peripheral refraction is affected by ocular rotation, although the effect shows considerable inter-subject variability and tends to be confined to those subjects with central myopia of -5.00D or more. Our results also suggest that any effect of ocular rotation is restricted to the peripheral retina with little measurable effect upon central refraction, irrespective of the degree of central myopia. However, the group difference in MSE before and after temporal fixation was not statistically significant.-

A study was conducted to measure peripheral refraction in the right eye of ten healthy, young subjects, either with eye rotation and head stationary or head rotation and eye stationary. They found no significant difference between the two methods in the effect of eye rotation for one minute upon peripheral refraction. The same authors conducted another experiment on 5 subjects using the same procedure with subjects viewing of off-axis targets for 2.50 minutes. However, they found no significant effect upon peripheral refraction with the longer viewing time [17].

It should be considered that the number of myopic subjects in both studies is low and likely to be too small to identify any effect with significance, and the peripheral viewing time is also short. Furthermore, accommodation and pupil diameter were uncontrolled which could affect the reliability of the measurements. In the current study, all the subjects were myopic and the use of longer fixation time for peripheral viewing was chosen to reveal any effect of eye muscle force upon refraction.

It should also be noted that the accuracy of head rotation is difficult to establish and taking an average of only 3 readings of refraction at each measurement position could affect both accuracy and reliability. In the current study we used an average of 10 measures of refraction which is known to be more accurate and used a specially modified table and chinrest, to allow instrument rotation with a high degree of accuracy. While the data of the present study is not conclusive, there is evidence of an effect of eye rotation upon peripheral refraction in the subjects with higher myopia (<-5.00D) which should be investigated further.

Using double pass technique, off axis refraction was measured in three different groups (11 emmetropes, 9 myopes, and 5 hyperopes), with ocular rotation up to 45˚ and head orientation straight. They found that the MSE of all groups were myopic at the periphery [5].

In this study, we used eye rotation of 20˚ along the horizontal meridian, whereas in their study it was 45˚. Our finding that there was some effect of eye rotation in the subjects with higher myopia combined with the findings of Seidemann., *et al*. above suggest that repeating the current study in subjects with myopia of -5.00D or more and using targets further off-axis may reveal greater differences in peripheral refraction due to the force of the extraocular muscles.

The relationship between OR and myopia is well established [24]. A recent study from our lab revealed that the lower rigidity of myopic eyes causes a significant decrease in the peak velocity of the eye during saccadic eye movements, particularly when the eye movements were 20˚ or more [18], suggesting that a difference in retinal profile might be found with 20˚ or more of rotation.

Moreover, it has been shown that myopic eyes might be expanded in all three dimensions [25], with the axial dimension being larger than the vertical or horizontal dimension [26]. Although large amounts of myopia are usually associated with increased eyeball size, high myopia is not associated with larger orbit size [27]. This could mean that the movement of a myopic eye is constrained by the limited size of orbital cavity, compared to emmetropic or hyperopic eyes.

Myopic eyes are less resistive to the force being generated by extra ocular muscles when eyes rotate [28]. In addition, Patel and co-workers reported that significant regional variations existed in anterior part of the sclera. As a consequence, some scleral areas are likely to be more liable to external forces than others [29].

When evaluating the results of earlier work on peripheral retinal profile to obtain off axis measurements using ocular rotation, the variations between studies in terms of methods as well as data collection should be considered. It is also possible that individual differences in some other factors such as choroidal thickness as well as ocular rigidity may also contribute to the variations between the studies.

## Conclusion

In summary, our data showed measurable changes in peripheral refraction as a result of ocular rotation, especially in subjects with myopia less than -5.00D. This suggests that the action of the extraocular muscles on the globe has a measurable effect upon retinal shape assessed by off-axis refraction in highly myopic subjects, although it appears to be restricted to peripheral retinal locations.

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