Evidence for transient forces/strains at the optic nerve head in myopia: repeated measurements of the Stiles–Crawford Effect of the First Kind (SCE-I) over time

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Abstract
Probable transient changes in photoreceptor alignments, inferred from the measurements of the Stiles–Crawford effect of the first kind (SCE - I), were demonstrated in myopic eyes with elongated axial length (regardless of the magnitude of refractive error) at three retinal locations; the fovea (point of fixation), and 22° and 27° in the nasal retina. The changes were much bigger at 22° and 27° in the nasal retina (which are located beyond the optic nerve head) than at the fovea. These transient effects were revealed by repeatedly testing the same retinal locations over a period of time. Time intervals between the subsequent/repeated measurements ranged from less than an hour to several months. In some locations, the changes were recorded in less than an hour. Collectively, these were very meaningful changes. Generally bigger effects were recorded in the horizontal SCE - I than in the vertical SCE - I.

Keywords: axial length, fovea, horizontal SCE - I, myopia, nasal retina, Stiles–Crawford effect of the first kind (SCE - I), vertical SCE - I

Introduction
Evidence of systematic strains on photoreceptor orientations in the presence of medium to high myopia was presented in an earlier study (Choi et al., 2003). In myopic eyes, the photoreceptors in the nasal retina (i.e. between the fovea and the optic nerve head) were found to be aligned towards the temporal edge of the optic disc instead of the centre of the pupil as in emmetropic eyes. The alterations in photoreceptor orientations [Stiles–Crawford effect of the first kind (SCE-I)] were found to be orderly and became greater with increasing myopia and eye size and length. The magnitude of alteration decreased from the temporal edge of the optic disc towards, and often included, the fixation point. To understand these effects better, modelling studies were conducted in Auckland and Madrid (Calvo et al., 2000). These studies revealed possibly stronger effects at retinal loci beyond, above and below the disc, and also, it was suggested that there might be associated scleral strains as well as mechanical stress centred just nasal to the insertion point of the optic nerve head. These may have been the underlying cause for the alignment of photoreceptors in the nasal retina among myopic and long eyes. Further modelling experiments using fibre optics underscored the possible extension of strains from the optic nerve head into the optic nerve equivalent (Calvo et al., 2000). Collectively, these findings suggested that there may be transient strains associated with ocular movements and pathophysiological manifestations of myopia such as twisted disc. To test these hypotheses, photoreceptor orientation about the optic nerve head has been investigated. In this study, the results from three retinal locations (22° and 27° in the nasal retina and fovea) are discussed. Additional aspects of these issues are also being studied.
Methods

The psychophysical technique employing the two-channel Maxwellian view system described by Enoch and Hope (1972) was employed to measure SCE-I functions. An orange background field subtending 4.5° with a 0.5° orange test field (Wratten filter 23A with illuminant A; Calumet, Chicago, IL, USA) superimposed upon its centre was used for the increment threshold measurements. This stimulus was projected into the pupil at seven different locations in 1-mm steps (i.e. 1, 2 and 3 mm from the pupil centre on either side and the pupil centre). At each pupil entry position, the subject was asked to match the brightness of the background field beam to that of the test field beam by adjusting the density of neutral density filters placed in the test stimulus pathway. Fourteen measurements, approaching from both non-seeing and seeing directions, were taken for each location of the pupil. Then the lowest and highest measurements in each group (i.e. non-seeing and seeing) were discarded. For the horizontal SCE-I function, the beam was driven horizontally through the pupil centre; similarly, the vertical SCE-I function was measured by translating the beam vertically. The position of the subject’s pupil and its size were continuously monitored throughout the experiment. To test different locations of the retina, different fixation targets were used.

As a means of testing the consistency of the subject’s judgement criteria, the increment threshold at the pupil centre was repeatedly measured before and after each displacement of the background field beam in the pupil. At each entry position, field stop adjustments were made as needed to maintain the concentric relationship between the background and the test fields.

The SCE-I functions were measured across time at three retinal loci, at 22° and 27° in the nasal retina (i.e. on the nasal side of the optic disc) and at fixation; 22° is close to the border of the disc. Initially, SCE-I measurements were repeated in random time sequences for each subject, and it was found that demonstrable changes in SCE-I functions occurred over time. This led us to conduct more systematic SCE-I studies using shorter and more regularly spaced measurement intervals within the same day. As a result of subjects’ different availabilities, the same-day measurements could not be made for all retinal locations on all subjects. The shorter measurement intervals ranged from 45 min to 2 h, which were determined based on individual observer’s difference rather than intent. It takes 45 min to complete a SCE-I measurement; therefore, the shortest interval was 45 min.

The repeated data sets on four subjects are presented here. They were one highly myopic anisometrope, one non-anisometropic high myope, one low myope and one emmetrope. Both eyes were tested on the highly myopic subjects, whereas one eye was tested on the low myopic and emmetropic subjects (Table 1).

All subjects were free of any retinal disorders other than the expected myopia-related changes such as myopic crescent, and their best-corrected vision was better than 20/20. The axial length of each eye tested was measured by using ultrasound A-scan. The subject’s pupil was dilated with 0.5% tropicamide. Informed consent was obtained from each subject prior to testing.

Results

Time-interval studies

The direction of photoreceptor alignment within a sampled area can be inferred by evaluating the peak position of SCE-I function, whereas the shape factor of the curve or the rho (ρ) value is known to reflect the distribution of alignments and packing characteristics of receptors within the area tested (Enoch and Hope, 1972). The commonly used Stiles equation was applied to all data sets (Enoch and Hope, 1972). Some of these data were not ideally fitted by this equation; however, for easier comparisons between different data sets, this relationship was used throughout. The horizontal SCE-I on different occasions are shown in Figure 1 (subject 1), Figure 2 (subject 2), Figure 3 (subject 3) and Figure 4 (subject 4).

All subjects, except for subject 1 who had the severest myopia in the group, showed temporal bias in photoreceptor alignment (with respect to the pupil centre) in

<table>
<thead>
<tr>
<th>Table 1. Refractive status and axial length of the eye for each subject and the retinal locations where the same-day repeatability was measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spherical equivalent refractive error (DS)</td>
</tr>
<tr>
<td>Subject 1: Highly myopic anisometrope</td>
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<tr>
<td></td>
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<tr>
<td>Subject 2: High myope</td>
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<td></td>
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<tr>
<td>Subject 3: Emmetrope</td>
</tr>
<tr>
<td>Subject 4: Low myope with long axial length</td>
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<tr>
<td>NR, nasal retina.</td>
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</tbody>
</table>

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Repeatability of SCE-I function along horizontal meridian at fixation for high myope

(-14.00 DS), OS

(a) Repeatability of SCE-I function along horizontal meridian at fixation for high myope

(-14.00 DS), OS

(b) Repeatability of SCE-I function along horizontal meridian at 22° NR for high myope

(-14.00 DS), OS

Figure 1. The horizontal SCE-I measurements in subject 1. The curves (from top to bottom) are sequentially displaced by 0.4 log units from each other to avoid overlap. The peak position of the SCE-I function is identified by the short vertical bar on each curve. The date/time at which each data set was obtained is shown in the legend. (a) OS (-14.00 DS) at fovea; (b) OS (-14.00 DS) at 22° nasal retina; (c) OS (-14.00 DS) at 27° nasal retina; (d) OD (-9.00 DS) at fovea; (e) OD (-9.00 DS) at 22° nasal retina; (f) OD (-9.00 DS) at 27° nasal retina.
Repeatability of SCE-I function along horizontal meridian at 27° NR for high myope (−14.00 DS), OS

Same day repeatability of SCE-I function along horizontal meridian at 27° NR for high myope (−14.00 DS), OS

Repeatability of SCE-I function along horizontal meridian at fixation for high myope (−9.00 DS), OD

Same day repeatability of SCE-I function along horizontal meridian at fixation for high myope (−9.00 DS), OD

Figure 1. (Continued). Also overleaf
the nasal retina, 22° and 27°, although the extent of misalignment varied over time (Figures 2c,e,f, 3b,c and 4b,c, and Table 2 for the summary of results). At fixation, the photoreceptors were more or less centrally aligned with much smaller degree of misalignments (both nasally and temporally) compared with those reported in the nasal retina (Figures 1a,d, 2a,d, 3a and 4a and Table 2 under fovea).

The peak positions and the Stiles rho (ρ) values of the SCE-I functions in the high myope with anisometropia (subject 1) and in the low myope with a long eyeball (subject 4) were found to be more variable than in the normal observer (subject 3). However, the non-anisometropic high myope (subject 2), who had uncharacteristically small myopic crescents, exhibited less variability in peak position locations and ρ values. All myopic subjects in this study had long axial length (see Table 1).

Major changes in peak and ρ values were observed at 22° and 27° in the nasal retina in both random and shorter time-interval experiments. At fixation, the SCE-I functions remained very much the same over time, unless the refractive error was highly myopic, except for subject 4 (Table 2, under fovea and Figures 1a,d, 2a,d and 3a). Subject 4 was a unique case in that the axial length was much longer than would be anticipated based on refractive error, and also the cornea was very flat, which must effectively compensate for the longer axial length. Therefore, in spite of a low degree of myopia, subject 4 has physiologically long eyeballs whose axial length is quite comparable with that of the very high myope (see Table 1). The results for this subject are discussed later.

It has been consistently shown that the longer the axial length of the eye, the greater the magnitude of variation in SCE-I functions in the nasal retina (at 22° and 27°) over time. In the −14.00 DS eye of subject 1, not only the peak position but also the overall shape of the curve changed drastically from measurement to measurement. On one occasion, the SCE-I function was classified very flat to inverted parabola (i.e. bent the other way), but during other times, it followed the more normal parabolic shaped curve. In some instances, these dramatic changes occurred within less than an hour (Figure 1b,c). Therefore, the ‘overall trend’ of the SCE-I functions could not be described by one mean number.

Figure 1. (Continued).
Repeatability of SCE-I function along horizontal meridian at fixation for high myope (–8.00 DS), OD

Repeatability of SCE-I function along horizontal meridian at 22° NR for high myope (–8.00 DS), OD

Repeatability of SCE-I function along horizontal meridian at 27° NR for high myope (–8.00 DS), OD

Same day repeatability of SCE-I function along horizontal meridian at fixation for high myope (–8.00 DS), OD

Same day repeatability of SCE-I function along horizontal meridian at 22° NR for high myope (–8.00 DS), OD

Same day repeatability of SCE-I function along horizontal meridian at 27° NR for high myope (–8.00 DS), OD

Relative increment threshold (log Cd m–2)

Horizontal SCE-I (2-9-01)
Peak: +0.05 mm
Rho: –0.05

Horizontal SCE-I (1-24-01, 3.00 pm)
Peak: +0.19 mm
Rho: –0.06

Horizontal SCE-I (8-24-00)
Peak: –0.02 mm
Rho: –0.06

Horizontal SCE-I (1-24-01, 3.00 pm)
Peak: +0.19 mm
Rho: –0.07

Horizontal SCE-I (1-24-01, 3.50 pm)
Peak: –0.31 mm
Rho: –0.05

Horizontal SCE-I (1-24-01, 12.45 pm)
Peak: –0.10 mm
Rho: –0.06

Horizontal SCE-I (1-25-01, 12.45 pm)
Peak: +0.67 mm
Rho: –0.06

Figure 2. The horizontal SCE-I measurements in subject 2. The curves (from top to bottom) are sequentially displaced by 0.4 log units from each other to avoid overlap. The peak position of the SCE-I function is identified by the short vertical bar on each curve. The date/time at which each data set was obtained is shown in the legend. (a) OD (–8.00 DS) at fovea; (b) OD (–8.00 DS) at 22° nasal retina; (c) OD (–8.00 DS) at 27° nasal retina; (d) OS (–8.00 DS) at fovea; (e) OS (–8.00 DS) at 22° nasal retina; (f) OS (–8.00 DS) at 27° nasal retina. Figure continued overleaf.
(d) Repeatability of SCE-I function along horizontal meridian at fixation for high myope (−8.00 DS), OS

Same day repeatability of SCE-I function along horizontal meridian at fixation for high myope (−8.00 DS), OS

(e) Repeatability of SCE-I function along horizontal meridian at 22° NR for high myope (−8.00 DS), OS

(f) Repeatability of SCE-I function along horizontal meridian at 27° NR for high myope (−8.00 DS), OS

Figures 2. (Continued)
for the peak position and the rho value: in this case, it would be described to be largely variable (see Table 2). At the fovea, the changes noted were smaller – all functions maintained their parabolic shaped curve although there were some variations in the peak positions and rho values (Figure 1a).

Figure 3. The horizontal SCE-I measurements in subject 3. The curves (from top to bottom) are sequentially displaced by 0.4 log units from each other to avoid overlap. The peak position of the SCE-I function is identified by the short vertical bar on each curve. The date/time at which each data set was obtained is shown in the legend. (a) OS (--0.25 DS) at fovea; (b) OS (--0.25 DS) at 22° nasal retina; (c) OS (--0.25 DS) at 27° nasal retina.
Same day repeatability of SCE-I function along horizontal meridian at fixation for low myope (–2.00 DS), OD

Relative increment threshold (log Cd m$^{-2}$)

Position at entrance pupil (mm)

(a) Repeatability of SCE-I function along horizontal meridian at fixation for low myope (–2.00 DS), OD

Horizontal SCE-I (4-9-01, 2.45 pm)
Peak: +0.33 mm
Rho: –0.05

Horizontal SCE-I (7-17-00)
Peak: +3.16 mm
Rho: –0.03

(b) Repeatability of SCE-I function along horizontal meridian at 22° NR for low myope (–2.00 DS), OD

Horizontal SCE-I (3-12-01)
Peak: +2.26 mm
Rho: –0.06

Horizontal SCE-I (7-17-00)
Peak: +3.16 mm
Rho: –0.03

(c) Repeatability of SCE-I function along horizontal meridian at 27° NR for low myope (–2.00 DS), OD

Horizontal SCE-I (4-4-01, 2.40 pm)
Peak: +2.08 mm
Rho: –0.06

Horizontal SCE-I (4-4-01, 2.40 pm)
Peak: +2.08 mm
Rho: –0.06

Same day repeatability of SCE-I function along horizontal meridian at fixation for low myope (–2.00 DS), OD

Relative increment threshold (log Cd m$^{-2}$)

Position at entrance pupil (mm)

Horizontal SCE-I (4-9-01, 3.30 pm)
Peak: +0.18 mm
Rho: –0.06

Horizontal SCE-I (4-9-01, 2.45 pm)
Peak: +0.33 mm
Rho: –0.05

Figure 4. The horizontal SCE-I measurements in subject 4. The curves (from top to bottom) are sequentially displaced by 0.4 log units from each other to avoid overlap. The peak position of the SCE-I function is identified by the short vertical bar on each curve. The date/time at which each data set was obtained is shown in the legend. (a) OD (–2.00 DS) at fovea; (b) OD (–2.00 DS) at 22° nasal retina; (c) OD (–2.00 DS) at 27° nasal retina.
**Table 2. Summary of results**

<table>
<thead>
<tr>
<th>Fovea (horiz. SCE-I)</th>
<th>22° NR (horiz. SCE-I)</th>
<th>27° NR (horiz. SCE-I)</th>
<th>22° NR (vert. SCE-I)</th>
<th>27° NR (vert. SCE-I)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subject 1 (LE: −14 D)</strong></td>
<td></td>
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</tr>
<tr>
<td>Peak position (mm)</td>
<td>−0.15 to +0.54</td>
<td>Linear, −3.05 to +2.26</td>
<td>−2.29 to +0.82</td>
<td>+0.78 to +1.49</td>
</tr>
<tr>
<td>$\rho$</td>
<td>−0.04 to −0.07</td>
<td>Linear, −0.03 to +0.02</td>
<td>+0.02 to −0.04</td>
<td>−0.01 to −0.03</td>
</tr>
<tr>
<td>Overall trend</td>
<td>Temporal, +0.28 mm, −0.05</td>
<td>Large variation</td>
<td>Large variation</td>
<td>Superior, +1.21 mm, −0.02</td>
</tr>
<tr>
<td>Shape</td>
<td>Parabola</td>
<td>Flat, parabola and</td>
<td>Flat, parabola and</td>
<td>Flat parabola</td>
</tr>
<tr>
<td>Fluctuation</td>
<td>Peak: Moderate</td>
<td>Peak: Marked ++</td>
<td>Peak: Marked ++</td>
<td>Peak: Moderate</td>
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<td></td>
<td>$\rho$: Moderate</td>
<td>$\rho$: Marked +</td>
<td>$\rho$: Marked +</td>
<td>$\rho$: Minimal</td>
</tr>
<tr>
<td><strong>Subject 1 (RE: −9 D)</strong></td>
<td></td>
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</tr>
<tr>
<td>Peak position (mm)</td>
<td>−1.32 to −1.72</td>
<td>−0.70 to −4.25</td>
<td>Linear, −2.31 to +2.85</td>
<td>Linear, +0.44 to +4.11</td>
</tr>
<tr>
<td>$\rho$</td>
<td>−0.03 to −0.05</td>
<td>+0.04 to −0.1</td>
<td>Linear, −0.02 to −0.04</td>
<td>Linear, −0.006 to −0.04</td>
</tr>
<tr>
<td>Overall trend</td>
<td>Nasal, −1.54 mm, −0.04</td>
<td>Large variation</td>
<td>Large variation</td>
<td>Large variation</td>
</tr>
<tr>
<td>Shape</td>
<td>Parabola</td>
<td>Flat, parabola and</td>
<td>Flat, parabola and</td>
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<tr>
<td>Fluctuation</td>
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<td>Peak: Marked ++</td>
<td>Peak: Marked ++</td>
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<td></td>
<td>$\rho$: Minimal</td>
<td>$\rho$: Marked +</td>
<td>$\rho$: Marked +</td>
<td>$\rho$: Minimal</td>
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<tr>
<td><strong>Subject 2 (LE: −8 D)</strong></td>
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<tr>
<td>Peak position (mm)</td>
<td>−0.31 to +0.19</td>
<td>−0.13 to +0.19</td>
<td>+0.53 to +0.90</td>
<td>−0.39 to −1.80</td>
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<tr>
<td>$\rho$</td>
<td>−0.05 to −0.07</td>
<td>−0.06 to −0.07</td>
<td>−0.05 to −0.06</td>
<td>−0.04 to −0.07</td>
</tr>
<tr>
<td>Overall trend</td>
<td>Central, −0.02 mm, −0.06</td>
<td>Temporal, −0.04 mm,</td>
<td>Temporal, −0.05</td>
<td>Infant, −1.17 mm, −0.05</td>
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<td>Shape</td>
<td>Parabola</td>
<td>Parabola</td>
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<td>Fluctuation</td>
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<td>$\rho$: Minimal</td>
<td>$\rho$: Minimal</td>
<td>$\rho$: Minimal</td>
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<tr>
<td><strong>Subject 3 (LE: EM)</strong></td>
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<tr>
<td>Peak position (mm)</td>
<td>−0.03 to +0.27</td>
<td>+0.38 to +0.80</td>
<td>+0.73 to +1.95</td>
<td>−0.21 to +0.28</td>
</tr>
<tr>
<td>$\rho$</td>
<td>−0.07 to −0.09</td>
<td>−0.04 to −0.08</td>
<td>−0.01 to −0.06</td>
<td>−0.04 to −0.07</td>
</tr>
<tr>
<td>Overall trend</td>
<td>Temporal, +0.09 mm, −0.08</td>
<td>Temporal, +0.60 mm,</td>
<td>Temporal, −0.06</td>
<td>+0.06 mm, −0.05</td>
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<tr>
<td>Shape</td>
<td>Parabola</td>
<td>Parabola</td>
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<tr>
<td>Fluctuation</td>
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<td></td>
<td>$\rho$: Minimal</td>
<td>$\rho$: Minimal</td>
<td>$\rho$: Minimal</td>
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<tr>
<td><strong>Subject 4 (RE: −2 D)</strong></td>
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<tr>
<td>Peak position (mm)</td>
<td>−0.37 to +0.33</td>
<td>+1.58 to +3.16</td>
<td>+1.61 to +3.53</td>
<td>−0.06 to −1.17</td>
</tr>
<tr>
<td>$\rho$</td>
<td>−0.04 to −0.06</td>
<td>−0.03 to −0.09</td>
<td>−0.03 to −0.08</td>
<td>−0.05 to −0.06</td>
</tr>
<tr>
<td>Overall trend</td>
<td>Central, +0.06 mm, −0.05</td>
<td>Temporal, +2.33 mm,</td>
<td>Temporal, −0.06</td>
<td>−0.68 mm, −0.05</td>
</tr>
<tr>
<td>Shape</td>
<td>Parabola</td>
<td>Parabola</td>
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<td>Parabola</td>
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<td>Fluctuation</td>
<td>Peak: Moderate</td>
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<td></td>
<td>$\rho$: Moderate</td>
<td>$\rho$: Marked +</td>
<td>$\rho$: Moderate</td>
<td>$\rho$: Moderate</td>
</tr>
</tbody>
</table>

**Peak position**: Range of peak positions of SCE-I functions in the entrance pupil: negative value = nasal and inferior displacement of receptors, positive value = temporal and superior displacement of receptors; linear means essentially flat SCE-I functions with no definable or quantifiable peak positions.

$\rho$ (Rho): Range of shape factor of SCE-I functions; positive value = inverted function, negative value = typical parabolic SCE-I function.

**Overall trend**: Trend of mean peak positions and rho values; temporal = temporal displacement, nasal = nasal displacement, superior = superior displacement, inferior = inferior displacement of peak positions.

**Shape**: General trend of measured SCE-I function shapes.

**Fluctuation**: Magnitude of variations of peak position and rho value of SCE-I functions. Peak position: 0–0.5 mm, minimal; 0.5–1.0 mm, moderate; 1.0–1.5 mm, marked; 1.5–2.0 mm, marked +; 1.75–2.0 mm, marked ++; 2.0–2.25 mm, marked +++; >2.25 mm, marked ++++; Rho value: 0–0.025, minimal; 0.025–0.05, moderate; >0.05, marked; linear and inverted parabola, marked++; NR, nasal retina.

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The less myopic eye of the two in subject 1 (−9.00 DS) also showed marked variations in SCE-I function over time in the nasal retina. The trend of variation was very similar to that of the more myopic eye. In the nasal retina, the SCE-I function changed from being a more typical parabolic shaped curve to a ‘reverse curve’ (i.e. bent the other way) (Figure 1e,f). It is possible that the reverse curve function might reflect a trough portion of a multi-peaked SCE-I. Therefore, the ‘overall trend’ of the SCE-I functions was described to be largely variable as in the left eye, instead of giving a mean number for the peak position and the rho value (see Table 2). Much smaller changes were observed at the fovea compared with the nasal retina at 22° and 27° (Figure 1d).

Surprisingly, the low myopic eye with longer axial length (subject 4) showed that the changes that are expected to be seen in much more highly myopic eyes. Although the SCE-I functions maintained the normal parabolic shaped curve throughout, both the peak position and the rho value of the function changed a great deal over a period of time in the nasal retina (Figure 4b,c). Again, much smaller variations were observed at the fovea (Figure 4a).

However, subject 2, who has a substantial amount of myopia in each eye (−8.00 DS OU), showed smaller variations in peak positions and rho values in the nasal retina than might have been expected (Figure 2a–f). Fundus examination revealed that subject 2 has exceptionally small myopic crescents (minimal) for −8.00 DS eyes. It is normally expected that as myopia increases, so does the size of the myopic crescent, which, in turn, is often used as a gauge of the magnitude of possible stress/strain around the optic nerve head induced by the myopia. Given this argument, and based on the size of the myopic crescents in subject 2, it appears that there are smaller stresses/strains exerted around the optic nerve heads. This hypothesis is supported by the findings in this study.

By comparison, most changes in the emmetropic subject were minimal except at 27° in the nasal retina (Figure 3a–c). When the transience of the horizontal and vertical SCE-I functions were compared, generally bigger effects were recorded along the horizontal meridian (i.e. horizontal SCE-I) than in the vertical meridian (i.e. vertical SCE-I). Only some of the vertical meridian results are shown here as examples due to space limitations. The results from subject 1’s right eye and subject 2’s left eye are shown in Figure 5a–d.

Repeatability of subject response

To ascertain the validity of observed variations in the SCE-I function over time, repeatability of subjective responses was tested on all subjects. This was achieved by repeatedly measuring the increment threshold at the pupil centre throughout the measurements. In all, seven sets of increment threshold measurements were made at the pupil centre during each single session. By checking the consistency of these seven measurements, one can determine whether the subject was using the same criteria of judgement during the entire period of data collection. They also made it possible to make comparisons based on relative assessments of consistency of performance.

All of these trained subjects in this study were found to be very reliable with very small variations between measurements. Figure 6 shows a typical data set demonstrating the consistency of increment threshold determinations made by subject 2.

Discussion and conclusions

Probable transient changes in photoreceptor alignments, inferred from the SCE-I measurements, were demonstrated in the eyes with elongated axial length, whether they were induced by myopia or from the eye just being physiologically long, regardless of the refractive error. As noted above, the Stiles–Crawford effect is known to be one of the most stable visual functions investigated (Enoch et al., 1999). For example, when measurements were repeated on one of the subjects reported by Enoch et al. (1973) after 35 years, the peak position of the function was found to be practically the same. Hence, finding the variations in the SCE-I functions in this study was a surprise. As noted, it was confirmed that all the subjects have been very reliable and careful in measuring increment thresholds throughout the experiments. Yet, these unexpected variations have been measured, especially among the subjects having elongated eyeballs.

These findings indicate that the observed fluctuations in SCE-I functions over time are indeed true, and that there appear to be both static and transient alterations in receptor alignments associated with, and induced by tractional forces acting at or near the optic nerve head. The trend has been that the receptors on the temporal side of the optic disc aligned nasally (and static) whereas the receptors on the nasal side of the optic disc aligned temporally (but transient) in myopic eyes with long axial length. This symmetrical change in alignment about the optic nerve head provides further support for the notion that the tractional strain/stress around or at the optic nerve head is the likely cause for both static and transient alterations in receptor alignments. In turn, disturbed alignments of receptors affect, to some degree, visual functions such as increment thresholds (Enoch et al., 2000). Clearly, further research is indicated to help understand the underlying causes of the measured effects. The findings

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in this study indicate that there is (are) meaningful tractional force(s) (both static and transient) extending across a substantial area of the retina with the origin near the optic nerve head.

Thus, in our ongoing studies, we seek to understand the underlying mechanisms inducing the detected tractional effects, both transient and static. We are mapping affected retinal areas, and assessing visual functions in those areas.

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