The relationship between refractive error and physical fatigue

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Abstract
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Degree Type
Thesis

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THE RELATIONSHIP BETWEEN REFRACTIVE ERROR AND PHYSICAL FATIGUE

By

WILLIAM TODD BRISCOE AND MICHAEL ANDREW COFFMAN

A thesis submitted to the faculty of the
College of Optometry
Pacific University
Forest Grove, Oregon
for the degree of
Doctor of Optometry
May, 1995

Advisor:

Thomas Samson, O.D.
Biography:

William Todd Briscoe is from the state of Montana. He graduated from Montana State University where he received a B.S. in biology. He served as an Infantry Officer with the U.S. Army and attended Pacific University on an Army scholarship. After graduation in 1995 he and his wife, Barbara Briscoe, O.D. will be stationed in Heidelberg, Germany. His interests are his wife and rock climbing.

Michael Andrew Coffman is from Eugene, Oregon. He attended the University of Oregon, Lane Community College, and received a B.S. in biology at Oregon State University in 1991. While attending Pacific University College of Optometry, Michael was active in student government. After graduation in 1995, he plans to acquire a private practice in Corvallis, Oregon. His interests include outdoor sports, music, and humor.
You can't fool nature.

RICHARD FEYNMAN
The Relationship Between Refractive Error And Physical Fatigue

ABSTRACT

The purpose of this study was to determine what type of refractive shift, if any, would occur as the result of enduring extreme physical fatigue. One hundred twenty-four marathon runners, and ten control subjects were measured with autorefractors before and immediately after the 26.2 mile Seattle marathon on November 27, 1993. The authors hypothesized that a significant shift in equivalent sphere toward hyperopia would occur due to the effects of dehydration, sympathetic activation, and possible loss of ciliary muscle tonus. The results indicate that there is no significant shift in refraction when compared to the controls, but individual subjects exhibited clinically relevant hyperopic or myopic shifts. Contact lens wearing subjects showed a statistically significant shift in refractive error towards myopia when compared to non-contact lens wearing subjects.

Key words: refraction, exercise, fatigue, marathon.
Acknowledgments:

The authors wish to thank the following individuals for their assistance on this endeavor: Barbara Briscoe, Theresa Cervinski, Bradley Coffey, Christine Gebhardt, Melissa Katsikis, Ken Loftus, and Cyrus Rad. Without their help this project might not have come to fruition.

We also wish to thank Beta Sigma Kappa and Westin® Hotels for their generous financial contributions, and the Seattle Marathon for allowing us to conduct this project.
The Relationship Between Refractive Error And Physical Fatigue

ABSTRACT
The purpose of this study was to determine what type of refractive shift, if any, would occur as the result of enduring extreme physical fatigue. One hundred twenty-four marathon runners, and ten control subjects were measured with autorefractors before and immediately after the 26.2 mile Seattle marathon on November 27, 1993. The authors hypothesized that a significant shift in equivalent sphere toward hyperopia would occur due to the effects of dehydration, sympathetic activation, and possible loss of ciliary muscle tonus. The results indicate that there is no significant shift in refraction when compared to the controls, but individual subjects exhibited clinically relevant hyperopic or myopic shifts. Contact lens wearing subjects showed a statistically significant shift in refractive error towards myopia when compared to non-contact lens wearing subjects.

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INTRODUCTION
This project was originally conceived when a slightly myopic optometry student showed a hyperopic shift in refraction the day after running in the Portland Marathon. Patient BH presented to the Pacific University Family Vision Center in Forest Grove, Oregon on 9/28/92
for a routine exam. Retinoscopy on this day showed plano -0.50 x 150 OD and plano sphere OS, and the subjective resulted in +0.25 -0.25 x 115 OD and +0.25 sphere OS. To corroborate these findings other refractive techniques were used. Previously, his yearly refractions yielded -0.50 sphere OU over a six year period. The refraction was re-evaluated in one month. This time the subjective showed -0.25 -0.50 x 170 OD and -0.25 - 0.25 x 128 OS. One year later the subjective refraction and retinoscopy showed -0.75 sphere OU. Various factors could have accounted for this shift in refraction, but the researchers felt that an investigation into the effects of exercise was warranted.

If indeed a shift in refraction could occur as the result of exercise, this information could be valuable to clinicians and researchers alike. A marathon was chosen as the test condition because the authors believe it would create a level of aerobic exhaustion greater than almost any other form of fatigue typically found in conventional forms of exercise or other activities. The body is not normally exposed to conditions that approach the extreme stress levels that occur during heavy exercise. The metabolism of the body during a marathon increases to 2,000% above normal.\(^1\) Physiological changes in the body during this form of exercise may affect the visual system in some way.

This information could be extrapolated to predict the effects of other forms of exhaustion as well. The visual effects of strenuous exercise, fatigue induced by military engagements, fire fighting, rescue work, and normal exercise workouts may be evaluated using the results of this experiment. Clinicians might consider special
refracting or prescribing paradigms for athletes and other individuals who subject themselves to physical exhaustion.

Another possible application of this research includes estimation of prescription change based on activity level. For example, in the case of BH, a practitioner must know if a refraction should be postponed until sufficient recovery time is allowed.

Other studies have reported shifts in visual acuity after exercise. In 1951, Krestovnikov reported a temporary increase in VA following a 1000 meter race. Seventy-three of the 100 male athletes showed an increase in VA. In 1972, Whiting reported improved VA after 10 minutes of table tennis in 39 male college students. Vlahov also showed a temporary increase in VA of five females after performing the Harvard step test in 1977. In 1983, Watanabe found slightly decreased static VA immediately after the start of exercise. There was no change from the initial value 4 to 15 minutes into the exercise, and no change 4 to 6 minutes after the exercise. Static VA showed improvement from the initial measurement 7 to 9 minutes following the exercise, and lasted until 21 minutes after ending the exercise. He evaluated 45 male students, excluding myopes and astigmats, while the subjects rode a stationary bicycle.

In 1991, Ishigaki evaluated ten male students on stationary bicycles for ten minutes. He found a kinetic VA deterioration just after exercise that slowly recovered. The degree of the deterioration was dependent upon the workload of the exercise.

These shifts in VA are not easily explained. Ishigaki also measured refractive error using an autorefractor and reported no
significant change in sphere or cylinder power. Ishigaki also demonstrated that the accommodative near point distance extended after exercise. This extension of the accommodative near point was related to the work load. Contrary to Ishigaki, Ritter and Huhn-Beck reported a statistically significant inward shift of dark focus in 12 college athletes after running a 400m race in 1993. Sympathetic nervous system activation was estimated by measuring pulse rate. Ritter and Huhn-Beck hypothesized that this inward shift of dark focus was due to activation of the sympathetic nervous system. The shift that Ritter and Huhn-Beck reported would seem to be in the opposite direction as predicted by sympathetic nervous system innervation.

Sympathetic activity inhibits the ciliary muscle by the beta adrenergic mechanism. Beta adrenergic drugs, such as epinephrine, inhibit the ciliary muscle. This causes a shift in refraction toward hyperopia.

Research is limited concerning physical fatigue and its effects on vision. Visual acuity change is the primary concern in most of these studies. No research dealing with this level of exhaustion and volume of subjects exists which assesses refractive error change.

The authors hypothesized that a person's refractive error would shift toward a more hyperopic position due to at least three factors: dehydration, sympathetic activation, and loss of ciliary body tonus.

The first factor is dehydration. Exercise causes dehydration of the body. During one hour of an endurance event an athlete loses five to ten pounds. Essentially all of this weight loss results from perspiration.
Dehydration causes decreased aqueous production. It sets up a hypertonic media for the lens. The capsule around the lens makes the lens act like an intact cell. The lens expands in hypotonic media and contracts in hypertonic media.\(^9\)

Dehydration of the lens causes a refractive shift toward hyperopia. On the other hand, acute myopia can be caused by increased hydration of the lens; for example, when the sorbitol pathway is used in response to increased levels of glucose.\(^{10}\)

The mechanism for this theorized shift involves aqueous formation by ultrafiltration. When the hydrostatic pressure of the blood plasma is reduced, ciliary body transport (ultrafiltration) is decreased.\(^9\) Since plasma is 91.5% water, and the osmotic pressure is raised during dehydration, a decrease in plasma volume would theoretically decrease aqueous formation by ultrafiltration.\(^{11}\) Adequate fluid ingestion during exercise can prevent this decrease in plasma volume.\(^{12}\)

The second factor is sympathetic nervous system activation. Exercise causes sympathetic activation of the body, and three different mechanisms enhance this effect.\(^{1,13}\) Simply thinking about exercise causes a psychic effect of exciting the autonomic nervous centers. Signals from motor cortex that innervate muscle send collateral signals into the vasomotor center to excite the entire sympathetic nervous system. Vasoconstriction occurs in most tissues of the body with the exception of the exercising muscles.\(^1\) Sensory nerve endings in the muscles are believed to be excited by metabolic products from muscle contraction. Signals from these nerves pass to
the vasomotor center to excite the sympathetic system even more, which further initiates mass sympathetic discharge.\textsuperscript{1,8}

The authors propose a third mechanism for a hyperopic shift. Considering the physiological changes in the body during extreme exercise, the authors suggest that the ciliary muscle will also be affected. The ultrastructure of ciliary muscle cells is different from other smooth muscle in many respects. The ciliary muscle resembles striated muscle physically, but can contract and relax rapidly due to a larger number of mitochondria. The second order parasympathetic neurons are located far away in the ciliary ganglion rather than within the organ itself. These neurons are large and resemble somatic motor neurons.\textsuperscript{14} Given the similarities to striated muscle, the effects of exercise on the ciliary muscle may be similar to that of skeletal muscle. Loss of ciliary muscle tonus, therefore, is the third theory for a hyperopic shift.

\textbf{METHODS}

The marathon began in Marymoor Park at 9:00 am, on Saturday, November 27, 1993. The finish line was located 26.2 miles away at the University of Washington campus. The researchers were stationed at a booth near the starting line before the race. After the race began, the equipment and research staff were transported to the booth at the finish line.

\textbf{SUBJECTS}

Runners in the Seattle marathon were contacted through the marathon coordinators with a written request that they participate in
this study. On the morning of the race, the subjects were recruited at the research station, located near the starting line. Ninety-six male subjects, and twenty-five females of various ages and ethnic origins were used for this experiment. Thirty-four subjects were contact lens wearers. Ten control subjects were enrolled in the study and did not participate in the race. As an incentive, the participants were entered into a raffle for three gift certificates donated by the Seattle Westin® Hotel.

APPARATUS

The researchers used two Canon RK II Autorefractors. The Canon RK II Autorefractor uses an infrared light beam bounced off the retina to obtain an objective measurement of the subject's refractive error. The instrument's photodetector receives and analyzes this beam.

Modern autorefractors are very accurate. According to the instrument's manual, the Canon RK II Autorefractor is accurate to within ± 0.12 diopters.

The station consisted of the two autorefractors with adjustable tables, and an enclosure to protect the instruments from the weather. The instruments were powered by a portable generator and protected with surge suppressers.

PROCEDURE

Autorefractor measurements were taken on both eyes of each participant and control subject. Contact lens wearers were identified and refracted while wearing their lenses. No specification was made
regarding lens type. The subjects were given a standardized instruction set. Measurements were repeated until at least three valid readings were obtained for each eye. Values were discarded if the autorefractor identified them as invalid or suspect. A colored sticker matched the runners to the autorefractor on which the initial measurements were taken.

After the race began, the researchers relocated their station to the finish line. The runners were assisted to the station immediately after crossing the finish line, and were measured on the same autorefractor by the same researcher. Again, measurements were taken until three valid values were obtained. The researchers took special measures to ensure the safety of the runners, considering their exhausted condition at the end of the race. The post-race measurement was taken no more than two minutes after each runner finished the race.

RESULTS

It was assumed that the effects of physical exertion upon refractive error would be symmetrical between the two eyes. Only data from the right eye of each subject was used for statistical analysis.

The mean equivalent sphere change for the experimental group was +0.064 diopters (sd=0.309), indicating a statistically significant shift toward hyperopia (p=.0236). The mean equivalent sphere change for the control group was +0.027 diopters (sd=0.186). This was not a statistically significant change.
The validity of this difference was determined by an unpaired two tailed t-test. The results showed that the difference between these values is not significant. In other words, this study found no significant difference in the change that occurred in the runners when compared to the change in the controls. (Table 1)

<table>
<thead>
<tr>
<th>Experimental Group</th>
<th>Number of Subjects (n)</th>
<th>Pre-Race Equivalent Sphere Average (Diopters)</th>
<th>Post-Race Equivalent Sphere Average (Diopters)</th>
<th>Change in Equivalent Sphere (Diopters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Subjects</td>
<td>124</td>
<td>-0.776 (sd=1.515)</td>
<td>-0.713 (sd=1.587)</td>
<td>+0.064 (sd=0.309)</td>
</tr>
<tr>
<td>All Controls</td>
<td>10</td>
<td>-1.102 (sd=1.679)</td>
<td>-1.075 (sd=1.719)</td>
<td>+0.027 (sd=0.186)</td>
</tr>
<tr>
<td>Female Subjects</td>
<td>25</td>
<td>-0.780 (sd=1.620)</td>
<td>-0.740 (sd=1.860)</td>
<td>+0.039 (sd=0.309)</td>
</tr>
<tr>
<td>Male Subjects</td>
<td>94</td>
<td>-0.80 (sd=1.46)</td>
<td>-0.73 (sd=1.64)</td>
<td>+0.065 (sd=0.315)</td>
</tr>
<tr>
<td>Female Controls</td>
<td>7</td>
<td>-1.19 (sd=1.66)</td>
<td>-1.21 (sd=1.85)</td>
<td>-0.024 (sd=0.139)</td>
</tr>
<tr>
<td>Male Controls</td>
<td>3</td>
<td>-0.90 (sd=1.47)</td>
<td>-0.75 (sd=1.66)</td>
<td>+0.147 (sd=0.260)</td>
</tr>
<tr>
<td>Contact Lens Subjects</td>
<td>34</td>
<td>-0.18 (sd=0.63)</td>
<td>-0.26 (sd=0.74)</td>
<td>-0.080 (sd=0.282)</td>
</tr>
<tr>
<td>Non-Contact Lens Subjects</td>
<td>90</td>
<td>-1.00 (sd=1.68)</td>
<td>-0.89 (sd=1.78)</td>
<td>+0.118 (sd=0.302)</td>
</tr>
<tr>
<td>Non-Contact Lens Controls</td>
<td>9</td>
<td>-1.24 (sd=1.72)</td>
<td>-1.22 (sd=1.76)</td>
<td>+0.020 (sd=0.196)</td>
</tr>
<tr>
<td>Group A: 3-4 hour finish</td>
<td>25</td>
<td>-0.79 (sd=1.29)</td>
<td>-0.73 (sd=1.44)</td>
<td>+0.058 (sd=0.372)</td>
</tr>
<tr>
<td>Group B: 4-5 hour finish</td>
<td>60</td>
<td>-0.81 (sd=1.76)</td>
<td>-0.73 (sd=1.85)</td>
<td>+0.074 (sd=0.299)</td>
</tr>
<tr>
<td>Group C: 5-6 hour finish</td>
<td>39</td>
<td>-0.72 (sd=1.26)</td>
<td>-0.67 (sd=1.23)</td>
<td>+0.053 (sd=0.281)</td>
</tr>
<tr>
<td>Myopic Subjects Eq. Sph &gt; -0.50</td>
<td>49</td>
<td>-1.96 (sd=1.72)</td>
<td>-1.88 (sd=1.82)</td>
<td>+0.082 (sd=0.283)</td>
</tr>
<tr>
<td>Hyperopic Subjects Eq. Sph &gt; +0.50</td>
<td>6</td>
<td>1.14 (sd=0.50)</td>
<td>1.34 (sd=0.94)</td>
<td>+0.202 (sd=0.460)</td>
</tr>
</tbody>
</table>

Table 1

Similar results were found when sphere values were evaluated. The runners showed a statistically significant shift toward hyperopia of +0.091 diopters (p=0.0008). Controls showed no significant change in sphere power. Furthermore, no significant differences existed between subjects when compared to controls in sphere values. (Fig1)
The subjects were then subdivided into categories based on gender, contact lens use, finish time, and pre-race refractive status. No differences were found between the ninety-four male runners and the twenty-five female runners. Furthermore, no significant difference existed between the gender groups and the controls. The gender of three subjects was unknown. (Fig 2)
The thirty-four contact lens wearing runners were compared to the ninety non-contact lens runners. The mean change in sphere and equivalent sphere was significantly different between the two groups. Contact lens wearers showed a myopic shift in equivalent sphere of -0.08 diopters, while non-contact lens wearers shifted +0.118 diopters towards hyperopia. Although the change between these groups is
statistically significant (p=0.0012), neither group is significantly different from the control. (Fig 3)

**Contact Lens Use**
Equivalent Sphere Change

The runners were subdivided into three groups based on the time they finished the marathon. Group A consisted of 25 runners who finished between three and four hours after the race began. Group B included 60 runners who finished in four to five hours. The
39 runners in group C finished between five and six hours. There were no significant differences between these groups. (Fig 4)

**Finish Time**
Equivalent Sphere Change

All the runners, excluding contact lens wearers, were subdivided according to pre-race refractive error. Subjects were categorized into hyperopic and myopic groups. A pre-race equivalent sphere value of greater than +0.50 diopters defined the hyperopes, and myopes were defined as having greater than -0.50 diopters. The
Six hyperopes had a mean equivalent sphere change of +0.202 diopters (sd=0.460), while the forty-nine myopes changed by +0.082 diopters (sd=0.283). The difference between these changes is not statistically significant. (Fig 5)

**Initial Refractive Error**

*Equivalent Sphere Change*

The largest single hyperopic equivalent sphere change in the subjects was +1.08 diopters. This change occurred in the most
hyperopic subject. The largest single myopic change was -0.69 diopters. (Fig 6)
Of the 124 runners, 49 had a change in equivalent sphere of at least 0.25 diopters. Thirty-two of those 49 shifted toward hyperopia, while 17 of the 49 moved toward myopia. Of all the subjects, 14 runners had a shift greater than 0.50 diopters. All of our subgroups (gender, contact lens wears, finish time, and refractive status) closely approximate the entire subject group distribution of equivalent sphere change.

DISCUSSION

The authors set out to discover why subjective vision changes have been reported by researchers and athletes alike. The authors hypothesized that there would be a shift in refractive error towards hyperopia. This study demonstrated that there was no significant change in the overall refraction of the subjects when compared to the control group. Even without comparison to the control group, the amount that did change was not clinically significant (+0.064 sphere). This amount is well below the documented average diurnal variations.\(^{16,17,18,19}\)

The contact lens wearing subjects exhibited a significant shift towards myopia. This may be due to physiological effects on the cornea resulting from drying of the contact lens. Swelling of the cornea can result from desiccation of rigid or soft contact lenses.\(^{20}\) This causes clouding of the stroma, and changes the corneal curvature. A small change in the front curvature can cause significant changes in the refractive error.\(^{20}\) Corneal edema from contact lens wear creates a steeper corneal surface, especially in rigid lenses.\(^{20}\) This creates a more myopic optical system. Although rigid lenses
mask most of the refractive changes while they are worn, other factors can contribute to these changes. Corneal thickness and index of refraction can change to a small degree with edema.\textsuperscript{20}

Previous researchers have demonstrated that there are visual changes that occur during and after exercise. The results of these studies are varied and inconsistent. The goal of this project was to discover a cause for the subjective visual changes reported by individual patients and researchers. Using the results of this study, it is unlikely that refractive error change is a cause of changes in VA reported in other studies. However, one must keep in mind that certain individuals in this study did exhibit changes which could be considered clinically significant.
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17. Santos VR. Morning to evening change in refraction, corneal curvature, and visual acuity 2-4 years after radial keratotomy in the perk study. Ophth Nov 1988; 951:487-93.


