THE EFFECT OF LIGHT INTESITY AND ACCOMMODATION ON SHORT-TERM OCULAR CHANGES IN MYOPES AND EMMETROPES

A thesis presented to the graduate faculty of
New England College of Optometry in partial fulfillment
of the requirements for the degree of Master of Science

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THE EFFECT OF LIGHT INTESITY AND ACCOMMODATION ON SHORT-TERM OCULAR CHANGES IN MYOPES AND EMMETROPES

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New England College of Optometry, 2015

PURPOSE

The purpose of this study is to investigate the effect of light intensity and accommodation on short-term changes in ocular components, specifically axial length and choroid, in myopic and emmetropic young adults after reading.

METHODS

Experiments were performed on 40 young adults with mean age ± SD = 23.88 ± 1.91 years. Distance refractive error and distance and near accommodation were measured using the Grand Seiko WR-5100K Autorefractor. Distance and near lateral phorias were determined using the Modified Thorington technique. Axial length [AL] was measured using the Haag-Streit Lenstar LS 900 at baseline and after the following conditions: reading in dim light (5-15 lux) with distance spherical equivalent refraction [SER], reading in dim light with distance SER and +2.00D add, reading in bright light (7,000-10,000 lux) with distance SER, reading in bright light with distance SER and +2.00D add. Choroidal thickness [ChT] was calculated independently by two investigators using data provided by the Lenstar. Repeated measures analyses of variance (ANOVA) was used to compare AL and ChT change with respect to baseline among the four conditions and between the two refractive groups.

RESULTS

There were 20 myopes with a mean SER of -3.71D, and 20 emmetropes with mean SER of +0.11D. For all subjects combined, there was no difference in overall mean AL at baseline and after reading under four conditions (p=0.40). However, there was a significant refractive group difference in mean AL change from baseline; for each condition the AL of myopes increased, while the AL of emmetropes decreased (p=0.01). Similar to the AL results, the ChT for all subjects combined was similar at baseline and across the four conditions (p=0.65). There was a significant refractive group difference in mean choroid change from baseline; for each condition the ChT of myopes decreased compared to baseline, while the ChT of emmetropes increased (p=0.02). AC/A ratios were not related to refractive error. The myopic and emmetropic refractive groups also did not differ in average hours spent outdoors, indoors, or on near work, whether during a school day, school weekend day, or summer day (all p-values > 0.05).

CONCLUSIONS

Over all reading conditions myopes showed an increase in axial length and a decrease in choroidal thickness compared to baseline, and emmetropes showed a decrease in axial length and increase in choroidal thickness. Dim versus bright lighting did not significantly affect changes in axial length, one of the main components related to myopia. Contrary to parental advice over generations, reading in dim light did not appear, at least in the short term, to have an adverse effect on eye growth.

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Introduction

Myopia is the leading cause of correctable vision loss throughout the world. The prevalence of myopia has increased, affecting up to 42% (Vitale, Sperduto, and Ferris, 2009) of young adults in Western countries and up to 80% of young adults in parts of Asia (Fredrick, 2002; Saw, 2003; Vitale, Cotch, Sperduto, and Ellwein, 2006; WHO, 2000). Furthermore, billions of dollars are spent each year for the treatment of myopia (Vitale et al 2006).

The specific etiology of refractive error, specifically myopia, is unknown; however, researchers have found both genetic and environmental correlates. For instance, children with two myopic parents are more likely to become myopic compared to children with no myopic parents (Pacella, McLellan, Grice, Del Bono, Wiggs, and Gwiazda, 1999; Jones, Sinnott, Mutti, Mitchell, Moeschberger, and Zadnik, 2007). Studies have also reported that various genetic loci and genes, such as the PAX 6 gene, may be associated with high myopia (Farbrother, Kirov, Owen, Pong-Wong, Haley, and Guggenheim, 2004; Tang, Rong, Young, Tam, Pang, and Chen, 2014). Near-work has long been considered the leading environmental contributor to myopia development and progression; however, the many variables associated with near-work do not always correlate with myopia (Ip, Saw, Rose, Morgan, Kifley, Wang, and Mitchell, 2006; Khader, Batayha, Abdul-Aziz, and Al-Shiekh, 2006; Mutti, Mitchell, Moeschberger, Jones, and Zadnik, 2002). For instance, questionnaire data do not show a link between hours of near work and refractive error, but other near-work related factors, such as reading distance, reading time, accommodation, and convergence,

seem to show an association with myopia (Bayramlar, Cekic, and Hepsen, 1999; Gwiazda, Thorn, Bauer, and Held, 1993; Harb, Thorn, and Troilo, 2006; Hepsen, Evereklioglu, and Bayramlar, 2001; Ip et al., 2006; Parssinen and Lyyra, 1993), although whether this association is causative is yet to be determined.

Though much of the data relating amount of near-work to myopia are based on questionnaires, there have been some studies which directly measure the effects of near-work on ocular components which may in turn lead to myopia development and progression. The presence of near-work induced transient myopia demonstrates that near work affects refractive error, at least in the short-term. A myopic shift occurs when distance refraction is measured after performing a near task (Ciuffreda and Ordonez, 1995; Ciuffreda and Wallis, 1998; Ciuffreda and Vasudevan, 2008; Vera-Diaz, Strang, and Winn, 2002). Other studies have shown that transient axial length changes can also be measured after tasks related to near-work. Mallen Kashyap, and Hampson (2006), Read, Collins, Woodman, and Cheong (2010), and Woodman, Read, and Collins (2012) found transient axial elongation during accommodation. Other parameters, such as lens thickness and anterior chamber depth, also changed with accommodation. Some of these studies hypothesize that transient axial elongation during sustained accommodation may help reduce hyperopic blur due to accommodative lag.

The modulation of axial length may in part be due to changes in choroidal thickness. Various studies that used chick eyes show that the choroid can expand or thin in order to compensate for retinal defocus (Nickla, Wildsoet, and Wallman, 1998; Wallman, Wildsoet, Xu, Gottlieb, Nickla, Marran, and Christensen, 1995; Troilo, Nickla, and Wildsoet, 2000).

Furthermore, human eyes with myopic refractive errors tend to have thinner choroids (Fujiwara, Imamura, Margolis, Slakter, and Spaide, 2009; Ikuno and Tano, 2009; Nishida Fujiwara, Imamura, Lima, Kurosaka, and Spaide, 2012). Flores-Moreno, Lugo, Duker, and Ruiz-Moreno (2013) found a high correlation, $r = -0.740$; $P < 0.001$, between choroidal thickness and axial length in highly myopic individuals, defined as a spherical equivalent worse than -6.00 diopters or axial length greater than or equal to 26 mm. Each millimeter of additional axial length corresponded to a 26 micrometer average decrease in choroidal thickness.

Some factors have been suggested to have a protective effect against myopia development and progression. These factors include taking breaks while reading, relaxing accommodation, increasing outdoor activity, and utilizing elevated light levels, but only accommodation has been studied directly. The COMET study (Gwiazda, Hyman, and Hussein, 2003) found that progressive addition lenses (PALs), which contain a +2.00D add, compared to single vision lenses, slowed myopia progression in children with large lags of accommodation and near esophoria, close reading distances, and more hours of near work.

Surveys have also found a correlation between more outdoor activity and less myopia; myopes tend to do fewer hours of outdoor activities compared to non-myopes (Deng, Gwiazda, and Thorn, 2010; Jones et al., 2007). The effect, however, may be due to elevated light levels found outdoors rather than the activity itself. In addition, surveys found that more total time spent outdoors, regardless of activity level, is associated with less myopia and more hyperopic mean refraction (Rose, Morgan, and Ip, 2008).

While there have been many questionnaire studies in human subjects that speculated that elevated outdoor light levels may contribute to the protective effect of outdoor activity against myopia, there has been little experimental research done on the effects of light intensity on myopia development and progression in humans. To date, there has been only one study which provided objective data showing a protective effect of outdoor light exposure against myopia. This study by Sherwin, Hewitt, Corone, Kearns, Griffiths, and Mackey (2012) measured conjunctival UV autofluorescnce (UVAF), which detects pre-clinical sunlight-induced UV damage, and used it as an objective measurement of ocular exposure to outdoor light and sun exposure. Furthermore, participants self-reported their time spent outdoors through a questionnaire. Both the UVAF and questionnaire data found a protective association of increasing time spent outdoors and less myopia; however, the UVAF association was stronger. Although the Sherwin et al study provided a good objective measure relating outdoor light and myopia, it was a cross-sectional study and prospective studies in humans are still needed to determine the relationship between light exposure and myopia.

Studies on the effect of light exposure on animal eyes provide insights relevant to human eye growth and myopia. Animal studies have shown that elevated light levels, whether caused by natural sunlight or artificial indoor light, retard form-deprivation myopia progression in chicks, tree shrews, guinea pigs and rhesus monkeys (Ashby, Ohlendorf, and Schaeffel, 2009; Ashby and Schaeffel, 2010; Siegwart, Ward, and Norton, 2012; Li, Lan, Yang, Liao, Xu, Lin, and Yang, 2014; Smith, Hung, and Huang, 2012). These studies induced myopia via either form-deprivation or minus lenses. Animals were then exposed to

various lighting conditions, with the bright lighting conditions ranging from 8,000 lux to 30,000 lux. Form- deprived animals exposed to elevated light levels had lower rates of myopia progression and axial elongation compared to those exposed to standard lighting. Contrastingly, animals with lens-induced myopia had varying results. A study using guinea pigs showed a protective effect of high-intensity lighting against lens-induced myopia (Li, Lan, Yang, Liao, Xu, Lin, and Yang, 2014). On the other hand, a study using monkeys, which have a close phylogeny and high homology with humans (Levkovitch-Verbin, 2004), found the same final refractive errors regardless of lighting condition (Smith, Hung, Arumugam, and Huang, 2013). Another study involving chicks showed a slower rate of progression, but no change in final refractive error with elevated light levels (Ashby et al., 2010). These results suggest different mechanisms involved in form-deprivation versus lens-induced myopia; the latter more closely resembles human myopia. Furthermore, studies investigating dopamine's role in myopia found that dopaminergic mechanisms behaved differently in form-deprivation and lens-induced myopia (Nickla and Totonelly, 2011; Schaeffel, Hagel, Bartmann, Kohler, and Zrenner, 1994; Bartmann, Schaeffel, Hagel, and Zrenner, 1994). For instance, Nickla et al., (2011) found that spiperone, a dopamine antagonist, prevented the ocular growth inhibition normally produced by brief periods of vision in form-deprived chick eyes. However, this effect was not seen in negative lens wearing eyes.

Purpose

The purpose of this study is to investigate the effect of light intensity and accommodation on short-term changes in ocular components, specifically axial length and choroid, in myopic and emmetropic young adults after reading.

Materials and methods

Subjects

Experiments were performed on 40 young adults with the following demographics: mean age ± SD = 23.88 ± 1.91 years; 9 males, 31 females; and ethnicity (self-reported): 18 Caucasian, 14 Asian, 4 Indian, 2 Hispanic, 1 Black, 1 other. There were 20 myopes with a mean spherical equivalent refraction [SER] of -3.71D in the right eye, ranging from -1.00 to -7.50D, and 20 emmetropes with mean SER of +0.11D, ranging from +0.50 to -0.50D.

Subjects were recruited from the New England College of Optometry. All participants had astigmatism ≤ 1.50D and anisometropia ≤ 1.00D. Contact lens wearers were required to have a back-up spectacle correction.

Subjects were excluded if they had a history of refractive surgery (e.g. LASIK) or orthokeratology (Ortho-K), strabismus, amblyopia, and/or current eye disease (pathology).

Apparatus

Distance refractive error and distance and near accommodation were measured using the Grand Seiko WR-5100K Autorefractor. This is a commercially-available, FDA-

approved, non-invasive measuring device that uses an open field of view to determine refractive error at any distance using any target. It has a measurement range of -8.25 to +7.25 D, and average intrasession repeatability has been shown to be 0.11 D for the spherical component and 0.13 D for the cylindrical component. Furthermore, approximately 50% of autorefractor measures were within +/- 0.25 D and 85% within +/-0.50 D of the spherical component of the prescription found by subjective refraction (Davies, Mallen, Wolffsohn, and Gilmartin, 2003).

Axial length and choroidal thickness was measured using the Haag-Streit Lenstar LS 900, an FDA-approved, non-contact optical device that measures ocular components using optical low-coherence reflectometry. According to the manufacturing specifications, the Lenstar's axial length measurement range is 14-32mm, with an in vivo repeatability of +/- 35 microns. Furthermore, the precision has been found to be 0.03mm +/- 0.02mm (Cruysberg, Doors, Verbakel, Berendschot, De Brabander, and Nuijts, 2010). Choroidal thickness can be calculated using the data provided by the Lenstar, and the method of calculation will be detailed later in this paper. Choroidal thickness measurements derived from the Lenstar have been shown to be highly correlated with SD-OCT measurements ($r^2 = 0.94$, $p < 0.0001$). Moreover, the measurements have a mean difference of 4 +/- 24 μm (Read, Collins, and Alonso-Caneiro, 2011).

Lighting conditions were measured with the Light Meter LX1010B, a commercially available light meter used for measuring the amount of light in lux of a given environment. It has a measurement range of 0 - 50,000 Lux, an accuracy of +/-5%, and a sampling rate of 0.4 seconds.

An Amazon Kindle Wi-Fi, 6" E Ink Display provided all reading material. This model Kindle had a standardized 10-point font. Furthermore, the E Ink Display did not have its own illumination source; therefore it was similar to paper in that it needed ambient illumination in order to be viewed.

Procedure

The Institutional Review Board at the New England College of Optometry approved this study, and all subjects provided written informed consent prior to starting the study. Subjects were asked to refrain from contact lens wear 24 hours prior to the start of and during the study. Prior to the start of the study, subjects completed a Clinical Data Questionnaire (appendix 1) as well as a Reading Habits and Activity Survey (appendix 2).

Subjects' distance refractive errors were determined by the Grand Seiko Autorefractor, and during testing all subjects were fitted with a trial frame containing their distance spherical equivalent refraction (SER). Distance and near lateral phorias were then determined using the Modified Thorington technique, with three readings taken at each distance. A horizontally-oriented Maddox rod was placed over the subject's left eye, who then reported the location of a vertical red line on a number/letter array (see appendix 3 for further details). An additional near lateral phoria measurement was taken while the subjects wore a +2.00D add over their distance SER. Accommodative measurements were taken (Grand Seiko Autorefractor) simultaneously with the phoria measurements. LogMar near visual acuities were taken on both right and left eyes while the subject wore their distance

SER and distance SER with +2.00D add. Baseline axial length was measured using the Haag-Streit Lenstar.

After all baseline measurements were taken, subjects were instructed to read from an Amazon Kindle under four different conditions. The experimental conditions consisted of:

1. Reading in dim light (5-15 lux) with distance SER
2. Reading in dim light (5-15 lux) with distance SER and +2.00D add
3. Reading in bright light (7,000-10,000 lux) with distance SER
4. Reading in bright light (7,000-10,000 lux) with distance SER and +2.00D add

Figure 1 shows the experimental setup, a constant 33cm reading distance was maintained by attaching the Kindle to a string tied to the trial frame. The subjects were instructed to hold the Kindle so the string remained taut. The lighting conditions were manipulated using compact fluorescent light bulbs (CFLs) placed in front of the subjects. The light intensity directly adjacent to the subject's left and right eyes was measured with the Light Meter LX1010B at the beginning, middle, and end of each reading condition. Dim lighting was maintained at an intensity ranging from 5-15 lux, while bright lighting was maintained at 7,000-10,000 lux.

The order of the four testing conditions was pseudo-randomized for each participant. The order was randomly picked out of a list of twenty-four possible permutations. Once a specific order was used, it was crossed off the list. Sixteen random reading orders were repeated after all twenty-four possible permutations were used. If a specific reading order

had to be reused, it was assigned to a subject belonging to the other refractive group. Each reading condition lasted for 15 minutes and ocular components were measured with the Lenstar immediately at the end of each condition. Subjects had a 5 minute break following the Lenstar measurements, and were instructed to refrain from doing any near-work. After the break, subjects repeated the procedure with the other conditions.



Figure 1: Experimental setup. Subject wore SER in trial frame and read from Kindle at 33cm under 4 conditions

Outcome Measures

The primary outcome of our study was change in axial length with respect to baseline. The secondary outcome was change in choroid with respect to baseline. Other outcomes included accommodative convergence and accommodation ratios, and hours spent outdoors, doing near work, and spent indoors on a typical school day, weekend day, and summer day.

Data analyses

Axial Length

Axial length (AL) was measured as the distance from the anterior corneal surface to the retinal pigment epithelium of the subject's right eye (Figure 2). Three to five consecutive measurements were taken at baseline and immediately after each experimental condition. Even though the Lenstar software provided an average axial length measurement, it included all measures, even unreliable ones, such as those taken during a blink; therefore, AL measurements were manually calculated after excluding measurements taken during blinks and those that differed by more than +/- 0.05mm from the majority of the measurements. The 0.05mm cut off was based on a study by Cruysberg, Doors, Verbakel, Berendschot, De Brabander, and Nuijts (2010) which evaluated the Lenstar and found the AL precision to be 0.03mm +/- 0.02mm. Repeated measures analyses of variance (ANOVA) were used to compare AL change with respect to baseline among the four conditions and between the two refractive groups, myopes and emmetropes.

Choroid

Choroidal thickness (ChT) was represented by the mean of three to five consecutive measurements taken at baseline and then immediately after each reading condition. Two independent experimenters, masked to the other's results, measured the choroid from Lenstar A-scan data (Figure 3) by manually measuring the distance between the retinal pigment epithelium (RPE) and the choroid sclera junction (ChSc). For discrepant choroid measurements, consensus was used to agree upon a measurement. Measurements were excluded from the average ChT if they lacked a RPE and/or a ChSc peak. Repeated measures analyses of variance (ANOVA) was used to compare ChT change with respect to baseline among the four conditions and between the two refractive groups. Linear regression was then used to investigate a possible correlation between AL change and ChT change.

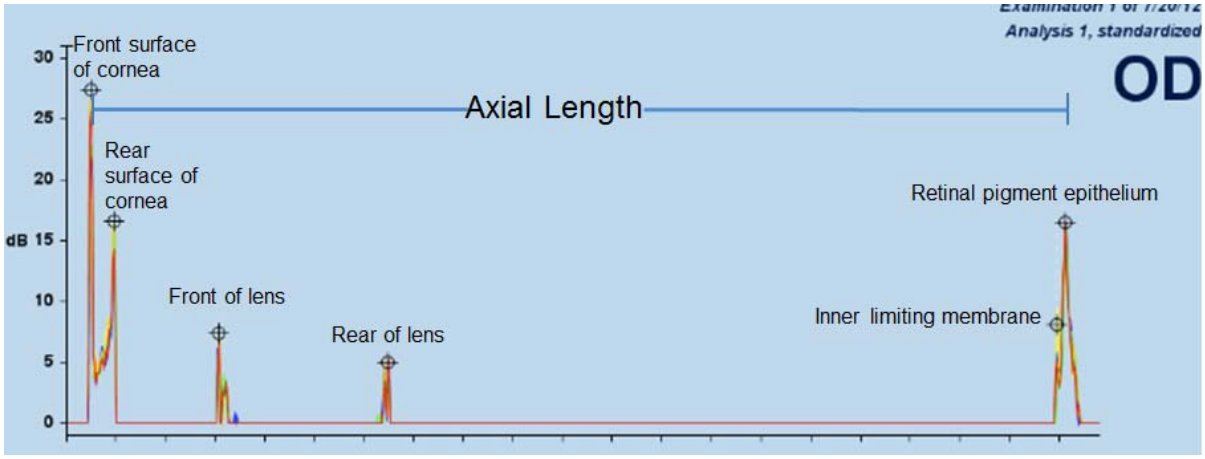


Figure 2: Lenstar biometer A-scan signal from entire eye. Axial length is measured as the distance from the front surface of the cornea to the retinal pigment epithelium.

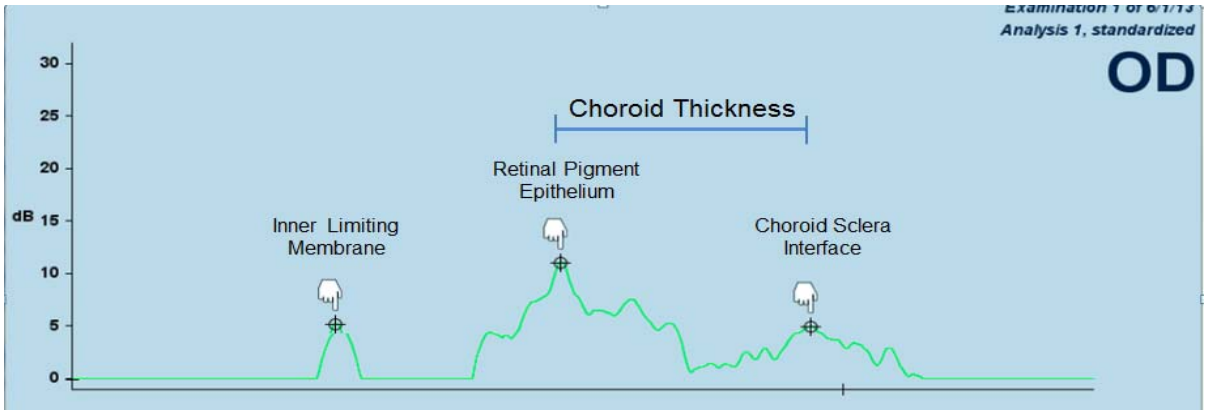


Figure 3: Magnified Lenstar biometer A-scan signal from the posterior portion of the eye. Choroid thickness is measured as the distance from the retinal pigment epithelium to the choroid sclera interface.

Accommodative convergence and accommodation ratio

Accommodation was measured for all subjects' right eyes during a distance and then a near viewing task. The spherical equivalent was calculated from an average of three accommodation measurements automatically generated by the Autorefractor. The final phoria measurement was calculated as an average of three readings taken by the Modified Thorington method described previously. The accommodative convergence/accommodation ratio (AC/A) was calculated using the stimulus and response techniques. The stimulus AC/A and response AC/A were calculated with the following formulas:

Stimulus AC/A= (PDcm x NearAS) - (FP-NP)/ NearAS

Response ACA= (PDcm x NearAS) - (FP-NP)/ -(NAR-DAR)

PD: pupillary distance in centimeters
NearAS: near accommodative stimulus, 3 diopters for all subjects
FP: far phoria, (-) used for exophorias and (+) for esophorias
NP: near phoria
NAR: near accommodative response
DAR: distance accommodative response

AC/A ratios with negative values or values greater than 20 were excluded from analyses since previous studies have shown they are unreliable and are likely a result of small accommodative responses or noise in the measurements (Ciuffreda, Rosenfield, and Chen, 1997; Gwiazda, Grice, and Thorn, 1999). Linear regressions were used to determine if there was a trend between refractive error and stimulus or response AC/A.

Outdoor activity, indoor activity, and near work hours

Self-reported questionnaires (see appendix 2) provided hours spent outdoors, doing near work, and spent indoors on a typical school day, school weekend day, and summer day for each subject. Outdoor hours included time spent with outdoor sports and leisure activities. Near work included time spent on video games, school work, reading, and computer use. Indoor hours included the near work hours as well as time spent on indoor sports, television, and classes. A subject's daily activity hours were computed as a sum of the previously mentioned categories for a typical school day, school weekend day, and summer day. Linear regressions were used to determine if there was a trend between the amount of refractive error and hours spent outdoors and indoors, or doing near work, on a typical school day, school weekend day, and summer day. Furthermore, two sample t-tests were used to test for refractive group differences in average hours spent outdoors, indoors and doing near work. Two-sample t-tests for unequal variance were used in cases of unequal variance between groups.

Results

Table 1 shows the gender and ethnicity distribution, as well as mean age, and mean right eye SER, for study subjects overall and separated by refractive group. The two refractive groups had similar gender distribution (p=1.0), ethnicity distribution (p=0.27), and mean ages (p=0.33). The mean SER for the myopic subjects was -3.71 +/- 2.07 D, while it was +0.11 +/- 0.34 D for the emmetropic subjects, and these values were significantly different (p<0.05).

TABLE 1: Summary statistics for subject demographics

Refractive Group Variable	**Total**	**Emmetropes**	**Myopes**	**p-value**
Gender [n (%)]				
Female	31	16 (80%)	15 (75%)	1.0[F]
Male	9	4 (20%)	5 (25%)	
Age *mean (SD)*	23.88 (1.91)	24.15 (2.06)	23.60 (1.76)	0.33[A]
Ethnicity [n(%)]				
Caucasian	18	10 (50%)	8 (40%)	0.27[F]
Asian	18	7 (35%)	11 (55%)	
Other	4	3 (15%)	1 (5%)	
Spherical equivalent refraction (OD)				
mean (SD)	-1.80 (2.43)	0.11 (0.34)	-3.71 (2.07)	<0.05[A]

F: Fisher's exact test
A: One-way ANOVA

Axial Length

For all subjects combined, there was no difference in overall mean AL at baseline and after reading under four conditions (p=0.40; Table 2). However, there was a significant refractive group difference in mean AL change from baseline; for each condition the AL of myopes increased, while the AL of emmetropes decreased (p=0.01; Fig 4).

TABLE 2: Mean axial length for baseline and reading conditions.

	Baseline	Bright +2D Add	Bright Distance SER	Dim +2D ADD	Dim Distance SER
Axial Length (mm) *mean (SE)*					
All Subjects	24.329 (0.179)	24.329 (0.179)	24.326 (0.180)	24.328 (0.179)	24.331 (0.180)
Emmetropes	23.529 (.129)	23.525 (.129)	23.523 (.130)	23.524 (.129)	23.526 (.130)
Myopes	25.129 (.217)	25.132 (.217)	25.130 (.218)	25.132 (.217)	25.136 (.218)

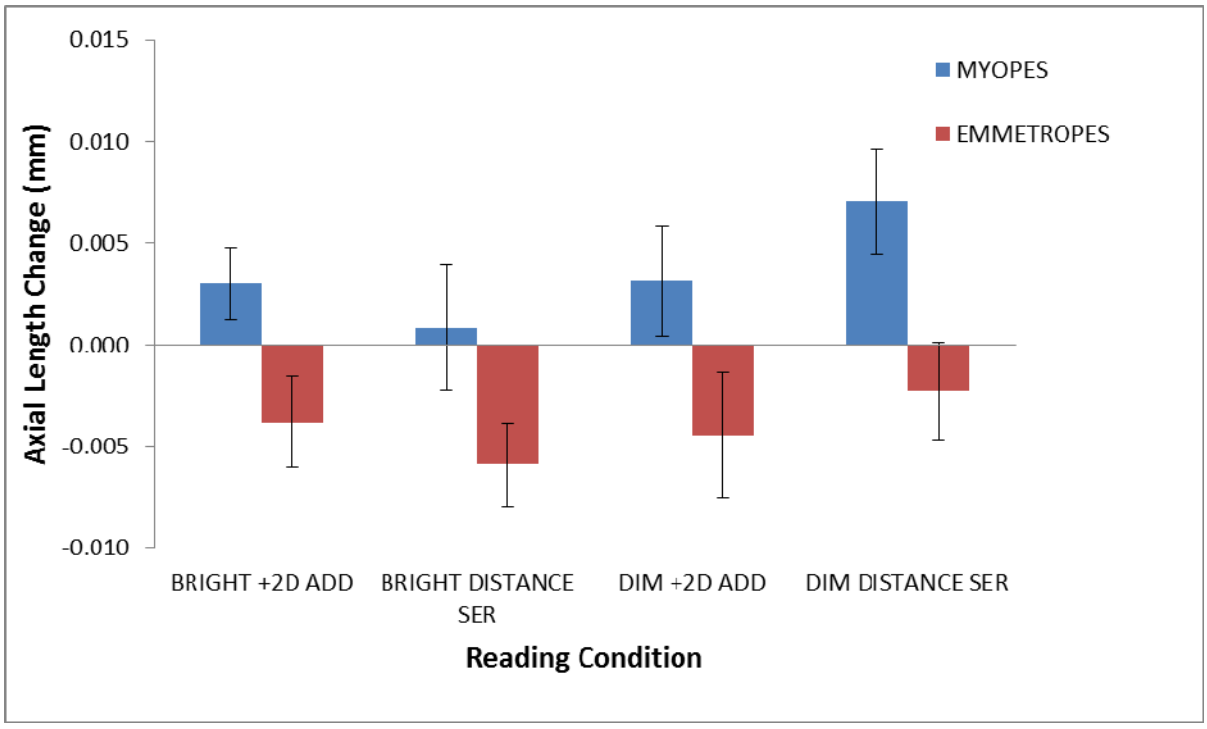


Figure 4: Axial length change following reading under four conditions for emmetropes (n=20) and myopes (n=20).

Choroid

Similar to the AL results, the ChT for all subjects combined was similar at baseline and across the four conditions (p=0.65; Table 3). However, there was a significant refractive group difference in mean choroid change from baseline; for each condition the ChT of myopes decreased compared to baseline, while the ChT of emmetropes increased (p=0.02; Fig 5).

The refractive group difference found in the choroid had an inverse relationship to that found in axial length; overall, emmetropes had a decrease in axial length and increase in choroidal thickness when compared to baseline, while myopes had an increase in axial length and decrease in choroidal thickness (Table 2 and 3). Although axial length and choroid measures had an inverse relationship, they did not perfectly compensate for one another. Linear regressions showed a weak negative correlation between changes in axial length versus changes in choroid thickness (Figure 6).

TABLE 3: Mean choroid change for baseline and reading conditions.

	Baseline	**Bright +2D Add**	**Bright Distance SER**	**Dim +2D ADD**	**Dim Distance SER**
Choroid (um) *mean (SE)*					
All Subjects	281.91 (12.22)	279.98 (12.41)	282.77 (12.65)	279.17 (12.45)	282.51 (12.32)
Emmetropes	274.80 (20.22)	279.54 (20.94)	283.14 (22.00)	280.95 (21.18)	286.49 (21.24)
Myopes	289.02 (14.09)	280.41 (13.91)	282.41 (13.17)	277.38 (13.69)	278.53 (13.04)

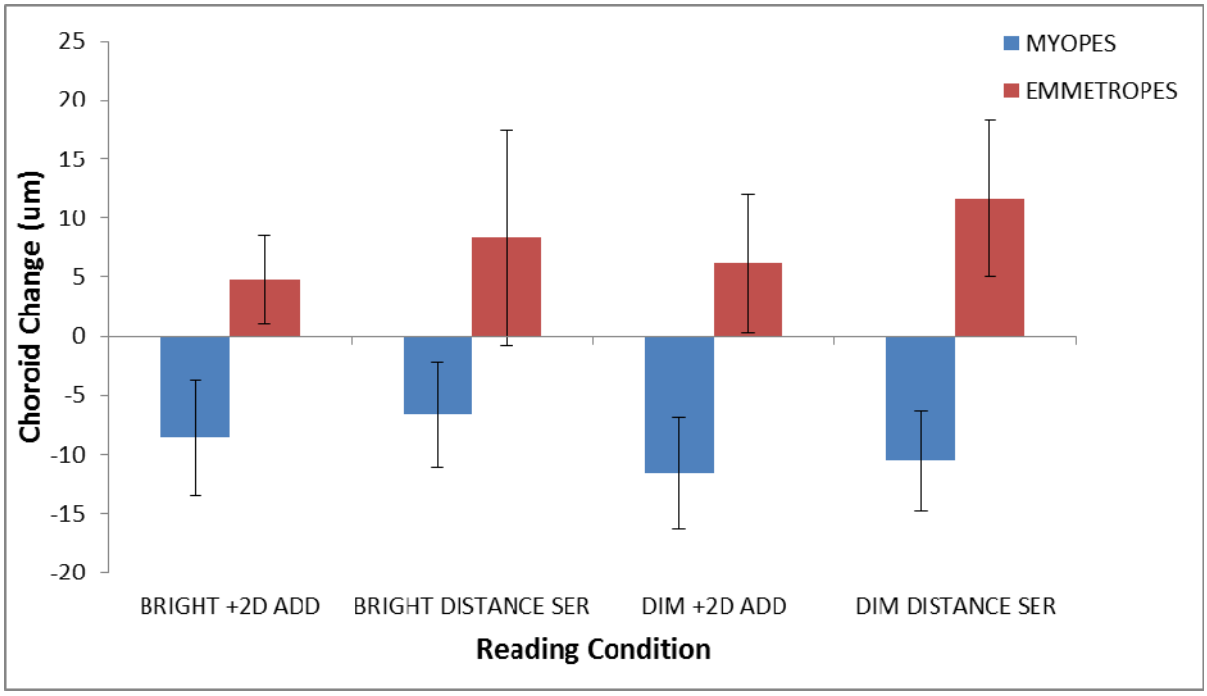


Figure 5: Choroid change following reading under four conditions for emmetropes (n=20) and myopes (n=20).

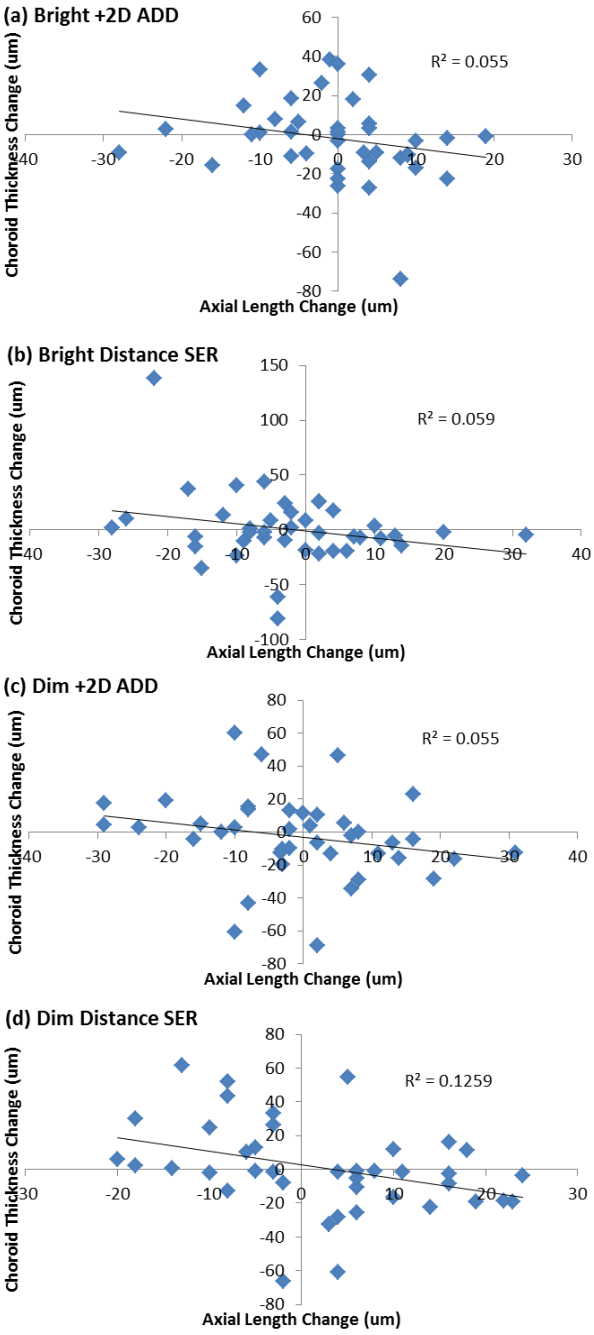


Figure 6: Change in axial length versus change in choroid for four conditions: (a) following reading in bright light with distance SER and +2.00D add, R^2=0.055, (b) reading in bright light with distance SER, R^2=0.059, (c) reading in dim light with distance SER and +2.00D add, R^2=0.055, and (d) reading in dim light with distance SER, R^2=0.126.

Accommodative convergence and accommodation ratio

There was a weak positive trend between more myopic refractive errors and increasing stimulus AC/A ratios, but it was not statistically significant (R^2=0.06, Fig 7). With respect to response AC/A ratios, as shown in Figure 8, there was no significant correlation with refractive error. Furthermore, 5 emmetropes and 7 myopes were excluded from response AC/A analysis due to either having a negative value or value greater than twenty.

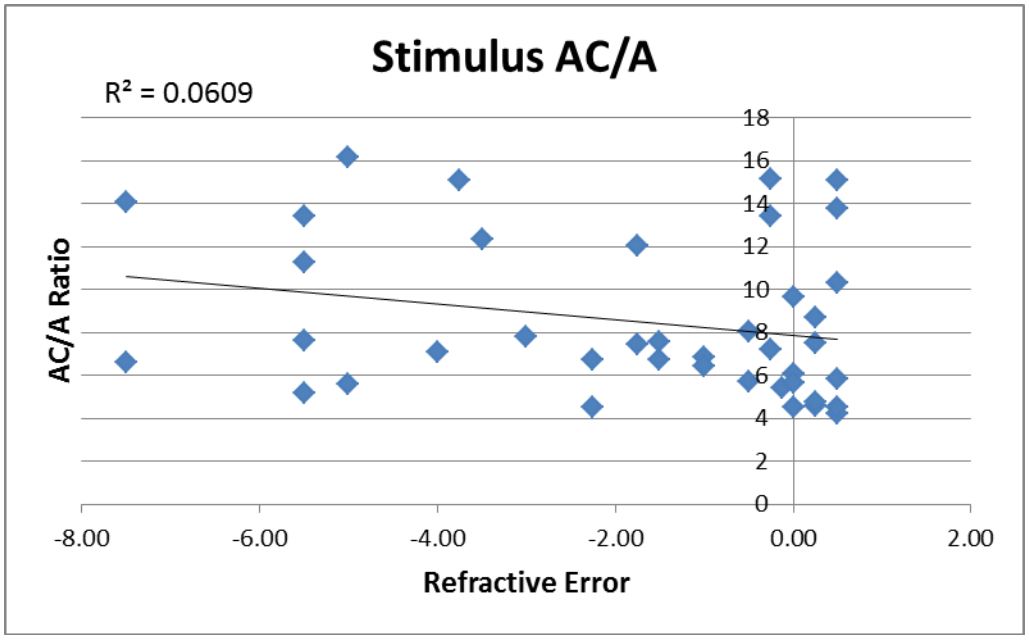


Figure 7: Stimulus AC/A ratios as a function of refractive error for emmetropes (n=20) and myopes (n=20), p>0.05.

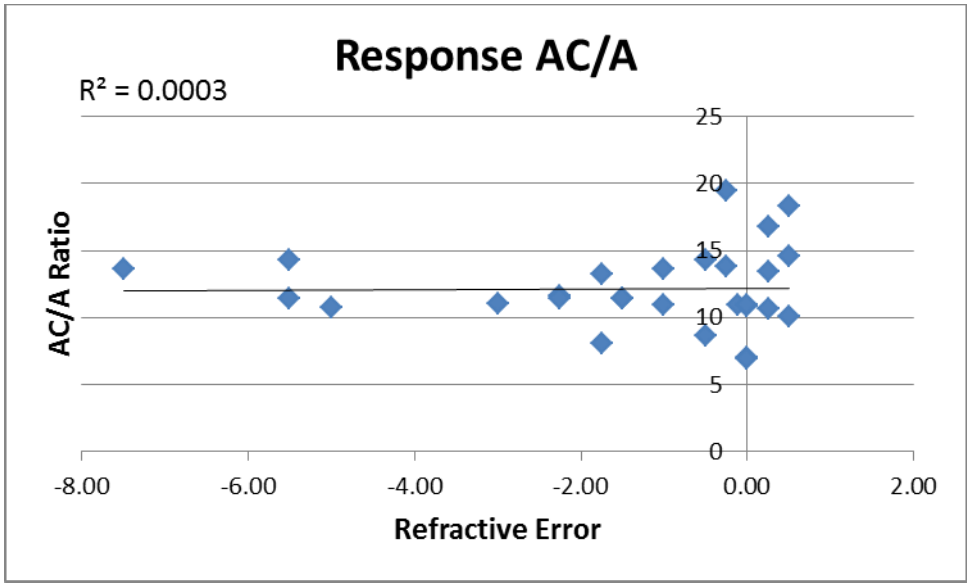


Figure 8: Response AC/A ratios as a function of refractive error for emmetropes (n=15) and myopes (n=13), p>0.05.

Outdoor activity, indoor activity, and near work

The refractive groups did not differ in average hours spent outdoors, indoors, or near work whether during a school day, school weekend day, or summer day, all p-values were >0.05 (Table 4). However, there was a weak positive trend between refractive error closer to emmetropia and more total hours of outdoor activity during a school weekend day (R^2 = 0.01, Fig 9a). A similar weak trend was seen between refractive error closer to emmetropia and fewer total hours spent indoors (R^2 = 0.02, Fig 9b) as well as fewer total hours spent on near work (R^2 = 0.01, Fig 9c), both during summer days.

TABLE 4: Average hours of outdoor activity (a), indoor activity (b), and near work (c) during a school day, school weekend day, and summer day (n=20 emmetropes, n=20 myopes), all p-values >0.05

(a) Average Outdoor Hours

	Emmetropes (n=20)	Myopes (n=20)	p-value
School Day	0.59 (0.95)	0.66 (1.09)	0.36
Weekend Day	1.11 (1.39)	1.06 (1.33)	0.41
Summer Day	1.55 (1.65)	1.58 (1.92)	0.46

(b) Average Indoor Hours

	Emmetropes (n=20)	Myopes (n=20)	p-value
School Day	5.475 (2.63)	6.1375 (2.50)	0.21
Weekend Day	2.925 (1.62)	3.3 (2.01)	0.26
Summer Day	3.15 (1.45)	3.8875 (2.79)	0.15

(c) Average Near work Hours

	Emmetropes (n=20)	Myopes (n=20)	p-value
School Day	6.15 (3.57)	5.8 (1.98)	0.35
Weekend Day	7.975 (3.31)	8.675 (3.33)	0.25
Summer Day	5.55 (2.31)	6.125 (3.01)	0.25

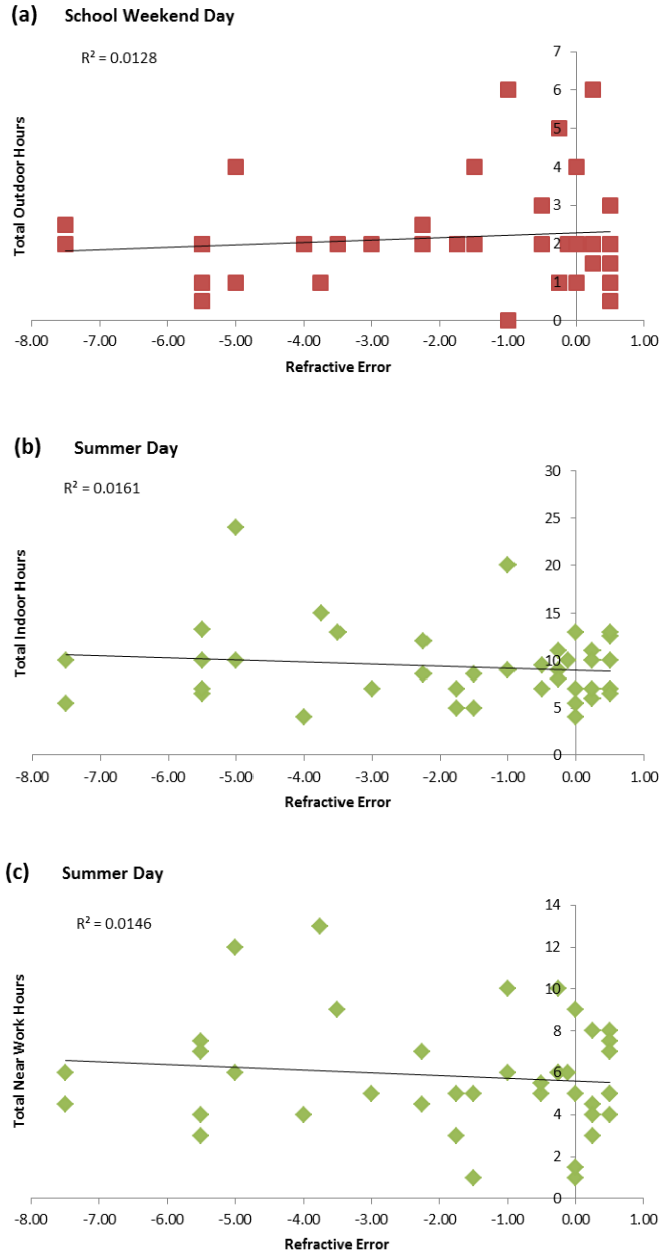


Figure 9: Refractive error versus total outdoor hours during a school weekend day, R^2=0.01 (a), total indoor hours during a summer day, R^2=0.02 (b), and total near work hours during a summer day, R^2=0.01 (c).

Discussion

Summary

After young adults read for 15 minutes at a time under bright and dim lighting conditions, as well as with distance correction and a +2.00 add, our main results showed that for all conditions, on average, myopes had a small increase in axial length when compared to baseline, while emmetropes showed a decrease in axial length. The choroid also demonstrated a small change; it thickened relative to baseline for emmetropes, and thinned relative to baseline for myopes. The refractive group differences in axial length and choroid measurements were both statistically significant. Moreover, the changes in the choroid had inverse relationships with axial length, but the measurements did not perfectly compensate for each other. Furthermore, the changes in axial length and choroid did not differ by either reading or lighting conditions within each refractive group.

Axial Length

This study showed that immediately after performing a sustained near task, regardless of light intensity or accommodative demand, myopes had a small increase in axial length while emmetropes showed a decrease in axial length. Some previous studies on accommodation and axial length (Mallen et al., 2006; Read et al., 2010) have found a transient increase in axial length, compared to baseline, for both myopes and emmetropes. These studies measured axial length while the subjects were actively accommodating; however, our study measured axial length immediately after completing the accommodative

task. Therefore, our study results can be better compared to those of Woodman et al., (2010 and 2012) where axial length was measured both during and after an accommodative task. Like the previously mentioned studies by Mallen et al (2006) and Read et al (2010), Woodman et al (2010 and 2012) found no statistically significant refractive group differences in axial elongation during the accommodative tasks. However, Woodman did find significant refractive group differences when axial length was again measured after completion of the accommodative task; myopes exhibited continued axial elongation, whereas the axial length of the emmetropes returned to their baseline measurements. Our study showed this general pattern for myopes; however, on average, our emmetropes did not return to baseline, but had decreased axial length compared to baseline. The refractive group difference in axial length found in our study and Woodman's suggest that myopes may require a longer time for recovery from accommodation-induced axial elongation. Therefore, there may be biomechanical differences between the myopic and emmetropic eye, for example in the choroid, discussed below.

Choroid

Like axial length, the choroid demonstrated a change after the reading task. In all four reading conditions, the choroid thickened relative to baseline for emmetropes and thinned relative to baseline for myopes. The changes in the choroid went in an opposite direction to axial length for both the emmetropes and myopes. However, the average amount of choroid change did not fully compensate for the axial length change in either refractive group. The relationship we found between the choroid and axial length measurements agrees

with human studies which show that axial length has the same inverse association with choroidal thickness in highly myopic subjects (Flores-Moreno et al 2013; Fujiwara et al 2009). Our results also agree with animal studies which show an inverse relationship between the choroid and axial length (Diether and Schaeffel, 1997; Nickla et al., 1998; Papastergiou, Schmid, Riva, Mendel, Stone, and Laties, 1998). For instance, chick eyes, which have diurnal variations in axial length, have thinner choroids during times of increased axial length. Nickla, Wildsoet, and Troilo (2002) found the same anti-phase relationship between axial length and choroid in juvenile marmosets but not in adolescent marmosets. Nickla, Rada, and Wallman (1999) proposed that axial length and the choroid could form part of a negative-feedback loop which senses refractive error fluctuations and causes changes in ocular growth.

Though the variations we found in the choroid explain part of the axial length change, the choroid measurements did not fully compensate for the axial length alterations. There could be other factors contributing to the axial length change. Some studies suggest that axial elongation is caused by an overall stretching of the entire globe (Drexler, Findl, Schmetterer, Hitzenberger, and Fercher, 1998; Mallen et al., 2006; Walker and Mutti, 2002). These authors theorize that during accommodation the ciliary smooth muscle contracts, causing an inward pull force to the choroid and sclera and a rearward displacement of the posterior portion of the globe, which leads to a transient increase in axial length. In regard to the decrease in axial length, animal studies have found active shortening of eyes through scleral remodeling (Zhu, McBrien, Smith, Troilo, and Wallman, 2013). These mechanisms

may explain a more permanent overall axial length change, but changes in the choroid are the likely explanation for the short term changes found in our study.

Light Intensity

Similar changes in axial length and choroid were found regardless of the light intensity during the reading conditions. There were no statistically significant differences in axial length or choroidal measurements between lighting conditions, either overall or by refractive group. Our results are consistent with those found in some animal studies which tested the effects of both artificial and natural lighting conditions at elevated levels on minus lens- induced axial myopia (Smith et al 2013; Ashby et al 2010). Smith et al found that infant monkeys with lens-induced myopia reared in different lighting conditions, ranging from 350 to 28,000 lux, did not differ at all in the course of refractive error change. Contrastingly, a recent study involving guinea pigs with lens-induced myopia (Li et al, 2014), and most studies involving chicks, tree shrews and monkeys with form deprivation myopia (Ashby et al., 2009; Siegwart et al., 2012; Smith et al., 2012), all showed that elevated light levels had a protective effect against myopia. For instance, Ashby et al., (2009) induced form-deprivation myopia in chicks and exposed them to different lighting conditions, either 500, 15,000, or 30,000 lux. Chicks exposed to the higher light levels had shorter axial lengths and corresponding less myopic refractions. However, the result of this study and others involving form deprivation myopia are less applicable to our study, as human myopia is rarely a result of form deprivation. Our results along with most lens-

induced myopia animal studies suggest that various lighting conditions, whether dim or bright, do not seem to alter ocular parameters, specifically axial length and the choroid.

Accommodative convergence and accommodation ratio

As previously discussed, our study found a decrease in axial length in emmetropes and an increase in axial length in myopes after reading. However, changes in accommodative demand did not seem to play a role in axial length or choroid change within each refractive group. There was no significant difference compared to baseline when subjects performed the near task through their distance correction versus through a +2.00D add. Theoretically, if accommodation alone were causing the changes in axial length, relaxing accommodation should affect axial length.

Studies such as the COMET study (Gwiazda et al., 2003, 2004) have found that progressive addition lenses, which contain a +2.00D add, compared to single vision lenses, slow myopia progression in children, especially those with large lags of accommodation and near esophoria. The treatment effect found in the COMET study was small, though statistically significant, and seen in pre-adolescent children. Therefore, our study may have not shown differences between the various accommodative conditions due to the short duration of the tasks and also the older age of our subjects.

Furthermore, there was no significant refractive group difference in stimulus or response AC/A ratios. This finding is consistent with a study that found that AC/A ratios were similar between myopic and non-myopic children (Mutti, Jones, Moeschberger, and

Zadnik, 2000). On the other hand, studies of children with progressing myopia have found elevated AC/A ratios in myopes compared to emmetropes (Gwiazda et al., 1999; 2005).

Outdoor activity, indoor activity, and near work

Our questionnaires showed that the myopic and emmetropic young adults have similar average hours of outdoor activity, indoor activity, and near work. This result is somewhat expected as our cohort of subjects all had similar backgrounds as optometry students with nearly identical class schedules, versus other studies which include children of different ages and education level. Though not statistically significant, our results showed a trend between more outdoor activity and less myopia, as seen in previous studies (Deng et al., 2010; Rose et al., 2008; Jones et al., 2007). Our subjects with larger myopic refractive errors showed a trend of slightly fewer hours of outdoor activity during weekend and summer days, and conversely, they also showed slightly more hours of near work during the same time periods.

Strengths and Limitations

One of the main strengths of this study is that it directly measured the effect of light intensity on short-term changes in axial length and choroidal thickness in human eyes. Previous research on light intensity and myopia has mostly used animal models. In human eyes a protective effect of increased light levels on myopia has largely been theorized based

on survey data of hours of outdoor activity in different refractive groups. Furthermore this study measured the effect of reading under more natural reading conditions, whereas previous studies measured ocular parameters after or during accommodation through a lens system. The repeated measures design of this study also helped negate possible confounding factors, such as diurnal variations in axial length and choroid thickness (Nickla et al., 2002; Chakraborty, R., Read, S., and Collins, M., 2011).

A limitation of this study is that it only utilized adult subjects. It is well established that refractive error tends to stabilize at approximately 15 to 16 years of age (COMET Group, 2013; Lin, Shih, Lee, Hung, and Hou, 1996; Goss and Winkler, 1983). Given that most of our subjects likely had a stable refractive error, their responses to the study conditions may be different than younger subjects with refractive errors that are changing, especially myopia that is progressing. Longitudinal studies in younger subjects with progressing refractive errors are needed to determine if lighting and accommodation affect long term refractive error. Additionally, our subjects tended to have high AC/A ratios mainly because many had large exophorias. The reason for this is unknown, but it could be related to the Modified Thorington technique used to measure phorias. Another limitation of the study was in the questionnaire data, which did not account for activities performed simultaneously (such as using the computer and going to class). Furthermore when subjects listed hours under the "other" category, many specified work but did not indicate whether that involved being indoors or outdoors. Therefore "other" hours were not accounted for in the total indoor and outdoor hours.

Clinical Implications

In the clinical setting, our results could potentially be used to ease parental concern over children reading in dim light as it does not seem to cause any short term ocular side effects. Furthermore, it is currently standard of care to recommend that myopic individuals take breaks while doing near work, which is also supported by our results. Our study showed increased axial length after reading in myopes, which may lead to axial myopia progression.

Conclusions

Over all reading conditions myopes showed an increase in axial length and a decrease in choroid compared to baseline, and emmetropes showed a decrease in axial length and increase in choroid. Our study showed that dim versus bright lighting did not significantly affect changes in axial length, one of the main components related to myopia. Changes in choroidal thickness may account for some of the changes in axial length. Altering accommodation during near work, specifically by relaxing accommodation with a spectacle near add, also did not produce differences in axial length compared to wearing the distance spherical equivalent correction. Contrary to parental advice over generations, reading in dim light does not appear, at least in the short term, to have an adverse effect on eye growth.

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Appendix 1:

Clinical Data Questionnaire

Clinical Data Questionnaire

INSTRUCTIONS FOR COMPLETION

Please answer the following questions that ask about demographic information as well as your general health and ophthalmic histories.

Testing Date (mm/dd/yyyy)	_____ (mm / dd / yyyy)
Full Name (First, middle initial, last)	_____ First MI Last
Date of Birth (mm/dd/yyyy)	_____ (mm / dd / yyyy)
Gender (Please circle one)	male female
Ethnicity **a.** Please select from the following the category that you believe best describes your ancestral ethnic heritage:	

1. American Indian/Alaska Native 2. Asian 3. Black/African American 4. White/Caucasian 5. Indian 6. Native Hawaiian/Pacific Islander 7. Other	**a.** _____
b. Are you of Hispanic or Latino descent? (Please circle one)	**b.** Yes No
c. If you selected 'Other' above, please describe your ethnic background.	**c.** _____

General Health	
a. Please list any medications you are currently taking, including over-the-counter (OTC) medications.	**a.** _____
b. Have you ever suffered a serious injury or illness? If so, please specify the approximate date(s) and nature of the incident(s).	**b.** _____ _____

Ophthalmic History	
a. Do you use corrective eyewear such as glasses or contact lenses? (Please circle one)	**a.** Yes No
i. If so, when did you first start wearing your corrective eyewear? (Year/Age)	**i.** _____ Year Age
ii. If so, are you nearsighted (have trouble seeing far away) or farsighted (have trouble seeing up close)? (Please circle one)	**ii.** Nearsighted Farsighted
b. Do you wear contact lenses? (Please circle one)	**b.** Yes No
i. If so, are your contacts considered 'extended wear'? (Please circle one)	**i.** Yes No
ii. If so, do you have a pair of back –up glasses	**ii.** Yes No
c. Have you ever been told you have a lazy eye, eye turn or squint? (Please circle one)	**c.** Yes No
d. As best you can, please specify your refractive error for both the right and left eyes (prescriptions can usually be found on your box of contacts, and may look similar to the example below)	**d.** **Right Eye (OD)** _____
Ex. Right Eye **(OD)** -6.75 -0.25 X 96 Left Eye **(OS)** +2.25 -0.75 X 180	**Left Eye (OS)** _____

e. Have you ever had Corneal Refractive Therapy (CRT) or Orthokeratology (Ortho-K)? (Please circle one)	**e.** Yes No
f. Have you ever had Laser Assisted In Situ Keratomileusis (LASIK) or Photorefractive Keratectomy (PRK)? (Please circle one)	**f.** Yes No
g. Do you regularly use eye drops? (Please circle one)	**g.** Yes No
h. Have you ever sustained an injury to either eye? (Please circle one) i. If so, for each injury please specify <u>which eye</u> and the nature and date of the injury.	**h.** Yes No **i.** _____ _____ _____
j. Do you currently have any eye diseases? (Please circle one)	**j.** Yes No

Additional Notes Are there additional considerations of which you think we should be aware? If so, please describe as succinctly as possible.	_____ _____ _____ _____ _____ _____ _____

_____

Your Name Printed

_____ _____

Your Signature Date

Appendix 2:

Reading Habits and Activity Questionnaire

Reading Habits and Activity Questionnaire

INSTRUCTIONS FOR COMPLETION

Please answer the following questions that ask about your reading habits and general activities. Please bring this completed questionnaire, along with the Clinical Data Questionnaire, to your appointment.

1) Where do you do most of your reading or near work?

☐ At home (e.g. bedroom, study)

☐ In the library

☐ Other (please describe) _____

2) What type of lighting is normally used when you read or do close work? Choose all that apply.

☐ Desk Lamp

☐ Ceiling or room light

☐ Natural light (e.g. sunlight through window, skylight)

☐ Other (please describe) _____

3) For how long do you continuously read or do near work before taking a break of 5 minutes or longer? Please estimate an approximate time in minutes.

_____ minutes of continuous reading/ near work

4) Do you normally wear glasses or contacts when reading or doing near work?

Glasses ☐ Yes ☐ No

Contacts ☐ Yes ☐ No

5) Do you get headaches when reading or doing near work?

☐ Yes ☐ No ☐ Don't Know

If yes, how often? _____ times per week.

6) How many books do you finish reading in a week?

_____books per week

7) What percentage of your reading is done from printed material versus electronic devices (i.e. Computer, Kindle, I-Pad, Nook)

_____% Printed Material _____% Electronic Device

8) Please estimate in hours the amount of time you spend doing the following activities:

	On a school weekday	**On a school weekend day**	**On a typical day in the summer or while not in school**
a) Indoor sports	_____ Hours	_____ Hours	_____ Hours
b) Outdoor sports	_____ Hours	_____ Hours	_____ Hours
c) Outdoor leisure (walking, picnic, etc.)	_____ Hours	_____ Hours	_____ Hours
d) Watching T.V., videos, etc.	_____ Hours	_____ Hours	_____ Hours
e) Playing video games	_____ Hours	_____ Hours	_____ Hours
f) Hobbies and crafts (drawing, painting, writing, etc.)	_____ Hours	_____ Hours	_____ Hours
g) Attending classes	_____ Hours	_____ Hours	_____ Hours
h) School work (outside of class)	_____ Hours	_____ Hours	_____ Hours
i) Reading books for leisure	_____ Hours	_____ Hours	_____ Hours
j) Using a computer (games, browsing, etc.)	_____ Hours	_____ Hours	_____ Hours
k) Sleeping	_____ Hours	_____ Hours	_____ Hours
l) Other_____ (Please specify)	_____ Hours	_____ Hours	_____ Hours

Appendix 3:

Modified Thorington Technique for Measuring Distance and Near Lateral Phorias

Modified Thorington Technique for Measurement of Distance Lateral Phoria and Near Lateral Phoria

Subjects wore a trial frame containing their distance spherical equivalent refractive error (SER) in front of the left and right eyes and a horizontally oriented Maddox rod in front of the left eye.

The subject fixated on the cross on the distance Thorington target (Figure A1) located 4 meters away and was reminded to keep the numbers and letters clear and be aware of the location of the vertical red line on the number/letter array. Without making any additional movement and without blinking, they were asked to state the number or letter which the red line had fallen or was closest. If the line fell directly on the dot located between the numbers or letters, the subject chose the higher number or letter. An accommodation measurement of the subject's right eye was then taken with the autorefractor before the subject indicated his/her response.

If on any reading the red line fell beyond the range of the Thorington target, the procedure was repeated with an 8pd (BI or BO as indicated) placed in the trial frame in front of the left eye, behind the Maddox rod. If the red line still fell beyond the range of the target with the added prism, it was recorded as "out of range".

The process was repeated for 3 readings on the autorefractor and 3 reports on the Thorington array.

The near lateral phoria and accommodation was measured using the same process as the distance lateral phoria, but with a rear-illuminated modified Thorington unit (Figure A2) mounted on a near-point rod of the Grand Seiko autorefractor at 33 cm from the subject's eyes.

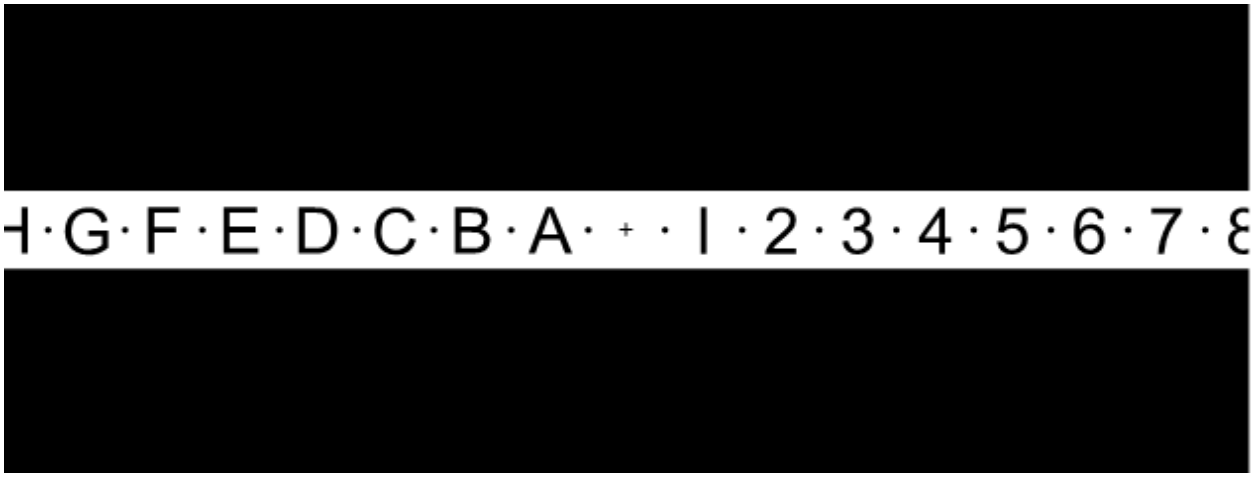


Figure A1: Pictorial representation of distance lateral phoria target

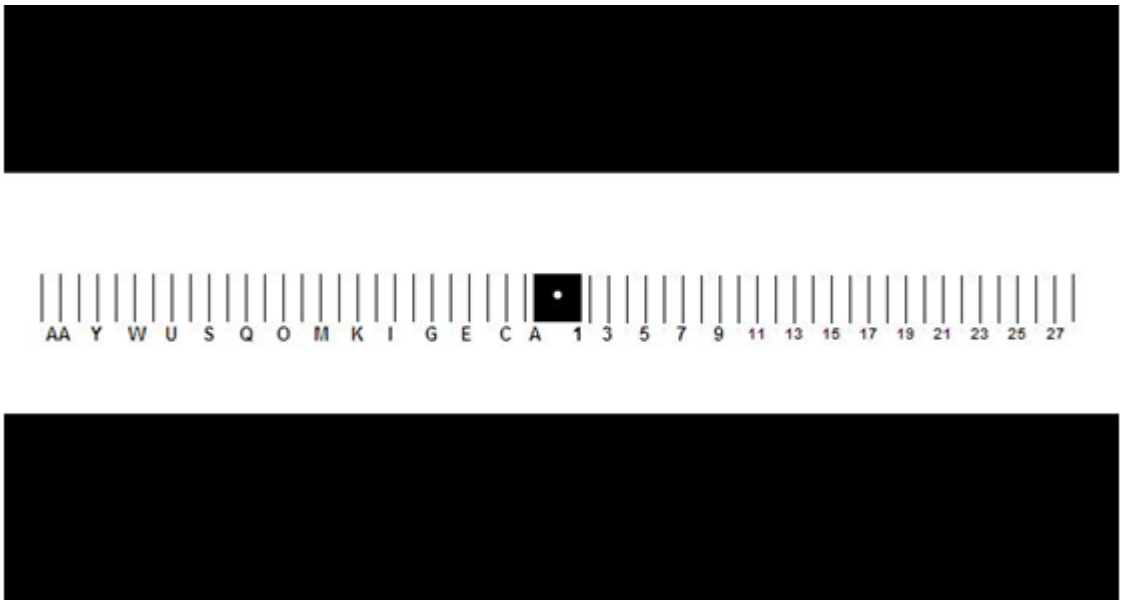


Figure A2: Pictorial representation of near lateral phoria target