REFRACTIVE GROUP DIFFERENCES IN OUTDOOR ACTIVITY IN CHILDREN AND YOUNG ADULTS

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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April, 2013

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PURPOSE

To investigate whether time outdoors or physical activity is more robustly associated with refractive error, and what, if any, association exists between relative peripheral refractive error and time spent outdoors, in children and young adults.

METHODS

46 young adults (mean age= 24.15±2.21 years) completed a visual activities questionnaire asking them to recall their daily activities at 10 years of age and currently, separately for winter and summer. Subjects indicated the average time spent daily on a variety of indoor and outdoor activities requiring either distance (e.g., exercise/sports) or near vision (e.g., reading). Hours of weekly activity were calculated as follows: (weekday hours x 5) + (weekend day hours x 2). All measures of refractive error were taken using the Grand Seiko WR-5100K autorefractor, under non-cycloplegic conditions. Myopia was defined as spherical equivalent refraction (SER) ≤ -0.50 D and non-myopia as SER between -0.49 D and +2.00 D. Peripheral refractive error (PRE) was measured centrally, 25˚ nasal, and 25˚ temporal retina. Refractive group differences in activity time and peripheral refractive error were compared using t-tests.

RESULTS

28 myopes (mean SER= -2.47±1.30 D) and 18 non-myopes (mean SER= +0.39±0.38 D) were tested. Overall, significant refractive group differences were found at 10 years, especially in outdoor physical activity. At 10 years, myopes spent significantly fewer hours per week in outdoor physical activity than non-myopes, both in the winter ($p=0.02$) and summer ($p=0.03$). At 10 years, myopes also reported significantly more hours of indoor near activity than non-myopes in the summer ($p=0.03$); winter hours were similar. The correlation between outdoor physical activity and indoor near activity in the summer was small and not significant ($R= -0.15$), suggesting no substitution effect. Myopes also had fewer total hours of physical activity (outdoor + indoor) at 10 years than non-myopes, but all subjects had similar hours of indoor activities. For the same activities at the current age, only one significant refractive group difference was found; myopes spent less time engaged in outdoor leisure activities during the winter than non-myopes ($p=0.02$). No significant association was found between relative PRE and time outdoors, when compared directly.

CONCLUSIONS

Refractive group differences in activity levels were found between myopes and non-myopes as children but not as young adults. These findings suggest that children spending more time outdoors during the winter and summer might develop less myopia. The data further suggest that being physically active is not the main source of these protective effects. Overall, the main clinical recommendation emerging from these results is to send children outdoors as often as possible.

ACKNOWLEDGEMENTS

I must first thank Dr. Jane Gwiazda, without whom none of this would have been possible. Thank you so much for your time, dedication and patience in guiding me through this process. I am so fortunate to have had such a gifted advisor, and I have learned more than you know in the past few years.

To the members of my committee, Dr. Deng, Dr. Scheiman, and Dr. Thorn, a special thank you for your collaborative efforts. I have very much appreciated your thoughtful suggestions and support throughout the project.

To my parents, Rich and Patti Brogan, thank you for always encouraging me to work hard, be myself and do my very best in all of my endeavors…even if that meant a few more sleepless nights from your child who turned procrastination into an art form. I would not be able to celebrate such an accomplishment without your constant love and support. To my family and friends, how blessed I am to have such caring people in my life, your support has meant so much to me over the years.

And most especially to my wonderful husband Andy, I truly could not have done this without you. Thank you for your endless support, advice, encouragement and love…from sitting as a study subject, to helping with data entry, to proof-reading my thesis. I am so very lucky to have such an amazing partner in this 'big adventure' we began together 3 years ago.

TABLE OF CONTENTS

Introduction 1

Purpose 7

Methods 7

- Subjects 7
- Apparatus 8
- Procedures 9
- Questionnaires 10
- Data Analysis 11
  - Refractive Error 11
  - Outdoor Activity 11
  - Peripheral Refraction 13
  - Statistical Analysis 14

Results 14

- Activities Analysis – 10 years old 15
- Activities Analysis – Current Age 21
- Activities Analysis – Comparison of 10 years old and current age 23
- Peripheral Refraction 27
- Relationship between outdoor activity and peripheral refraction 28

Discussion 30

- Outdoor Activity 30

Outdoor versus physical activity 31

The role of near work 32

Seasonal differences in activity and myopia progression 33

Possible mechanisms 34

Peripheral refraction 35

Strengths and Limitation 36

Conclusions 37

References 38

Appendices 41

Appendix 1: Activities Questionnaire 41

Appendix 2: Clinical Data Questionnaire 56

FIGURES

FIGURE NUMBER	FIGURE TITLE	PAGE
1	Experimental set-up for peripheral refraction	9
2	Weekly outdoor physical activity at 10 years old	19
3	(a) Paired Activity: Outdoor Physical Activity vs. Indoor Near Activity in the Winter at 10 years old	20
	(b) Paired Activity: Outdoor Physical Activity vs. Indoor Near Activity in the Summer at 10 years old	20
4	Weekly outdoor physical activity at the current age	23
5	(a) Total physical activity hours per week during the winter	25
	(b) Total physical activity hours per week during the summer	25
6	Age of first ocular correction	26
7	Relative peripheral refractive profile in myopes and non-myopes	28
8	Relative peripheral refractive error vs. total hours of outdoor activity in the summer at 10 years old in myopes and non-myopes	29

TABLES

TABLE NUMBER	TABLE TITLE	PAGE
1	Subcategories used in analysis of the Activities Questionnaire	12
2	Mean central SER, age, and gender distribution of all subjects (n= 59), those included (n= 46) and those excluded (n= 13) from further data analysis	14
3	Mean central SER, age, and gender distribution for subjects (n= 46) included in data analysis, separated by refractive error	15
4	Weekly activity hours for subjects at 10 years of age	17
5	Weekly activity hours for subjects at their current age	22
6	Mean (±SD) measured peripheral refractive error, for all subjects and by refractive error group	27

INTRODUCTION

With the reported rise in the prevalence of myopia (Vitale, Sperduto, and Ferris, 2009), continued research to discern the mechanisms underlying myopia becomes increasingly important. It is well understood that myopia is often accompanied by a number of sight-threatening long-term sequelae secondary to the eye's increased axial length, including some forms of glaucoma, chorioretinal degenerations and retinal detachment, which increase in risk proportionately to the amount of myopia (Saw, Gazzard, Shih-Yen, and Chua, 2005). In order to develop effective treatments, it is imperative that we understand the factors contributing to the development and progression of myopia, particularly those environmental factors which we may be able to manage.

The most notable non-environmental risk factor is family history of myopia. A number of studies have shown that children with two myopic parents are more likely to develop myopia than children with zero or one myopic parents (Pacella, McLellan, Grice, Del Bono, Wiggs, and Gwiazda, 1999; Mutti, Mitchell, Moeschberger, Jones, and Zadnik, 2002). The odds ratio of becoming myopic with two versus one or zero myopic parents was reported as 6.42 by Pacella et al. (1999), with Mutti et al. (2002) finding a similar ratio of 6.40 of developing myopia with two versus zero myopic parents. Myopia is more prevalent in those of East Asian descent; one study estimates that 73.9% of teenagers in Singapore are myopic (Quek, Chau, Chong C., Chong J., Hey, Lee, Lim, and Saw, 2004). Because we cannot modify our family history or ethnic background we need to investigate environmental risk factors that can be changed.

A factor that is easy to control is the time children spend engaged in outdoor activity, a recently reported potential protective factor, assuming that children spend sufficient hours outside. Myopic children are reported to spend less time doing outdoor activities than non-myopes (Deng, Gwiazda, and Thorn, 2010; Mutti et al., 2002; Rose, Morgan, Ip, Kifley, Huynh, Smith, and Mitchell, 2008; Jones, Sinnott, Mutti, Mitchell, Moeschberger, and Zadnik, 2007; Ip, Saw, Rose, Morgan, Kifley, Wang, and Mitchell, 2008; Dirani, Tong, Gazzard, Zhang, Chia, Young, Rose, Mitchell, and Saw, 2009; Jones-Jordan, Mitchell, Cotter, Kleinstein, Manny, Mutti, Twelker, Sims, and Zadnik, 2011; Guggenheim, Northstone, McMahon, Ness, Deere, Mattocks, Pourcain, and Williams, 2012). A recent meta-analysis of myopia and outdoor activity (Sherwin, Reacher, Koegh, Khawaja, Mackey, and Foster, 2012) found an odds ratio showing a protective effect of outdoor activity similar to results from the individual studies included in the analysis.

It is still unknown whether the key factor related to the development of myopia is lack of time outdoors or physical activity. Even though most of the current literature agrees that there is a protective effect of outdoor activity on myopia development, based on questionnaire data, the questions asked about sports and outdoor activity have not consistently been structured in a way to differentiate between being outdoors and being active.

Mutti et al. (2002) assessed visual activities of children enrolled in the Orinda Longitudinal Study of Myopia (OLSM), by asking how many hours outside of school the child spent engaged in various activities, including sports/outdoor activities. This cross-sectional study made no distinction between indoor and outdoor sports, or between physical

activity and organized sporting events. The results showed that myopic children spent less time engaged in sports/outdoor activities than emmetropic children. A longitudinal investigation by the same research group showed that fewer hours of sports/outdoor activity were associated with incident myopia (Jones et al., 2007). In addition, this report showed that children with two myopic parents who spent at least 14 hours per week on outdoor activity were able to overcome their genetic predisposition to more myopia.

One of the few studies to separate being outdoors from physical activity via questionnaire asked children (or their parents) to report the number of hours they spent during a typical day performing a given activity (Rose et al., 2008). The questionnaire contained separate categories for outdoor activities, indoor activities, and tasks performed at far, mid-working and near distances, concluding that the key factor providing the protective effect against myopia was being outdoors, rather than being physically active. A follow-up study by French et al. (French, Morgan, Mitchell, and Rose, 2013) found the results of this questionnaire to be similar in two different cohorts of 12 year olds, again concluding that being outdoors (and not physical activity) was the protective factor, and that children's activities became more myopigenic with age. Also recently, Guggenheim et al. (2012) reported that for children enrolled in the Avon Longitudinal Study of Parents and Children (ALSPAC), time outdoors was a stronger protective factor than exercise.

Only one study investigated the role of physical activity (and not being outdoors) in myopia development. Jacobsen et al. (Jacobsen, Jensen, and Goldschmidt, 2008), in a longitudinal study of Danish medical students, asked study participants to complete a questionnaire about the amount of time spent reading, using a computer, and the average

number of hours per week spent exercising in the past 6 months. While myopia was shown to have a negative association with physical activity, these findings may have been confounded by outdoor activity, since a considerable portion of the students' physical activity came from bike riding to and from school, as is common in Denmark.

With no clear agreement in the literature, it remains to be determined whether it is being outdoors, physical activity or some combination of the two that is responsible for the protective effect against myopia observed in human eyes.

The results of animal studies point to a significant role for light in the development of myopia. Chicks exposed to high light levels, both natural and artificial (Ashby, Ohlendorf, and Schaeffel, 2009), have been shown to exhibit shorter eyes and less myopic refractive errors than those reared under normal lighting conditions. The light exposure was found to retard growth of the eye, rather than lack of light increasing eye growth from form-deprivation myopia. Smith et al. (Smith, Hung, and Huang, 2012) performed a similar experiment on infant monkeys, with analogous results, but only for form-deprivation myopia. High light levels accompanied more hyperopic refractive errors, with the non-human primates showing more robust protection from form deprivation myopia than the chickens. However, the protective effect of light did not extend to negative lens-induced myopia, which is more relevant to human myopia (Smith, Hung, Arumugam, and Huang, 2013). Multiple explanations have been proposed to describe what mechanisms might be involved in this protective effect. Neuromodulators are thought to play a role, with dopamine, released in response to light-sensitive amacrine cells, acting as a potent growth inhibitor. It is also

postulated that because light causes pupillary constriction and increases depth of field, the resultant decrease in image blur hinders growth signals.

Both animal and human work shows that light is important in terms of refractive development. In addition to lack of outdoor activity, another risk factor often cited in association with myopia development in children is excessive near work. Significant findings relate myopia to closer reading distances and continuous reading (Ip et al., 2008), reading a greater number of books (Saw, Chua, Hong, Wu, Chan, Chia, Stone, and Tan, 2002), and liking to read (Williams, Miller, Gazzard, and Saw, 2008). A common assumption might be that children not spending time outside could be indoors studying or doing other activities at shorter working distances, and under dimmer lighting conditions. This suggests the existence of a substitutive effect, where time that might have been spent outdoors is instead 'substituted' for indoor activities, including those at near working distances. However, the literature has not found this to be true (Rose et al., 2008; Mutti et al., 2002; Deng et al., 2010).

All of the above results are related to central refractive errors. The influence of peripheral refractive errors on myopia development and progression has also been studied (review by Charman and Radhakrishnan, 2010). An early study (Hoogerheide, Rempt, and Hoogenboom, 1971) examined the peripheral refractive profiles of emmetropic and mildly hyperopic young adult pilots. Those individuals with relative hyperopia in the periphery were more likely to develop central myopia than the subjects with relative peripheral myopia, over an unspecified follow-up period. The interpretation of Hoogerheide et al. (1971) has recently been questioned by Rosén et al. (Rosén, Lundström, Unsbo, and Atchison, 2012), due to the

timing of the measurements for relative peripheral refractive profile, with respect to the initial visit.

Monkey data agree with the results of Hoogerheide et al. (1971). Smith and colleagues found that even with foveal ablation in infant monkeys, the emmetropization process still occurred (Smith, Ramamirtham, Qiao-Grider, Hung, Huang, Kee, Coats, and Paysse, 2007). Moreover, when relative hyperopia was induced in the peripheral retina, eyes became centrally myopic (Smith, Hung, and Huang, 2009). These results suggest that the peripheral retina in non-human primates has the capacity for regulation of eye growth. However, two recent studies of peripheral refraction in children (Mutti, Sinnott, Mitchell, Jones-Jordan, Moeschberger, Cotter, Kleinstien, Manny, Twelker, and Zadnik, 2011a; Sng, Lin, Gazzard, Chang, Dirani, Lim, Selvaraj, Ian, Drobe, Wong, and Saw, 2011) reported that prevalent but not incident myopes had more relative peripheral hyperopia than non-myopes. Both studies, involving American (Mutti et al., 2011a) and Singapore Chinese (Sng et al., 2011) children, found relative peripheral hyperopia to occur more often in myopic than emmetropic children. However, neither study found relative peripheral hyperopia to precede or predict the progression of myopia.

Based on all these previous studies, it remains unknown whether a key protective factor related to myopia is being outdoors or physical activity, and what association, if any, the peripheral refractive profile has with outdoor activity.

PURPOSE

The current study aims to determine if time outdoors or physical activity is more strongly associated with refractive error. It also aims to explore the potential association between relative peripheral refractive error and time spent outdoors. We propose the following hypotheses:

1. Myopic individuals spend less time outdoors than non-myopic individuals
2. The number of hours spent engaged in physical activity is similar between myopic and non-myopic individuals
3. Individuals spending less time outdoors will demonstrate more relative peripheral hyperopia

METHODS

Subjects

Fifty nine young adults (26 male, 33 female), ages 18 to 30 years participated in the study. As most subjects were optometry school students, recruitment was by email through the New England College of Optometry; non-optometry school subjects were recruited via an advertisement on Craigslist. Inclusion criteria were: spherical equivalent refraction (SER) between -6.00 D and +2.00 D, less than 1.50 D of astigmatism, and less than 1.00 D of anisometropia (as determined by SER), with no history of strabismus, amblyopia, refractive surgery/treatment (e.g., LASIK, orthokeratology), or current eye disease (e.g., keratoconus,

diabetic retinopathy, glaucoma, etc.). Each subject provided their written informed consent prior to beginning the study. The project was approved by the New England College of Optometry's (NECO) Institutional Review Board and followed the tenants of the Declaration of Helsinki.

A power analysis indicated that 85 subjects were needed to detect a moderate correlation between hours of outdoor activity and refractive error with 80% statistical power and significance at the 0.05 level. However, due to logistical limitations only 59 subjects were enrolled in the study.

Apparatus

All study measurements of refractive error were made using the Grand Seiko WR-5100K autorefractor (Hiroshima, Japan), under non-cycloplegic conditions. The instrument's open field of view design allows real targets of any size to be placed at any distance, reducing instrument-induced myopia. Similar targets were used for each set of study measurements. Subjects viewed a single line of 5 back-lit high contrast 20/100 Sloan letters at 4m for central (foveal) refractive error, at 2m for all peripheral refractive measurements (central, 25° nasal, and 25° temporal) (Fig. 1), and at 33cm for accommodative response measurements. Axial length measurements were taken using the Carl Zeiss IOL Master (Peabody, MA).

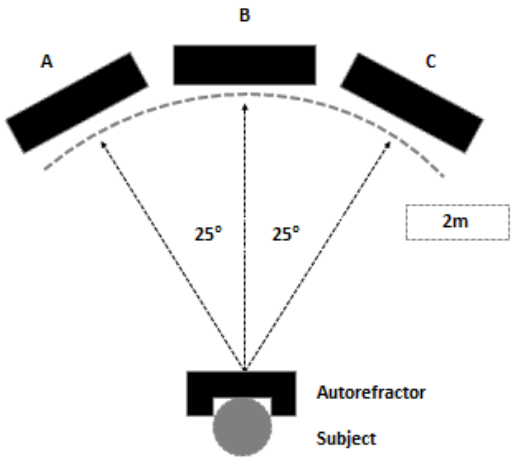


Figure 1. Experimental set-up for peripheral refraction. Measurements were taken in three locations: (A) 25˚ nasal retina, (B) centrally, and (C) 25˚ temporal retina of the right eye.

Procedures

To determine eligibility for the study, central refractive error (minus cylinder form) was measured on both eyes; three measurements were taken for each eye. All lenses used for subsequent study measurements were based upon the SER of this measure.

Peripheral refraction was measured without correction. Three measurements were taken at each of the three positions (central, 25° nasal, and 25° temporal) for the right eye only; the left eye was occluded. Subjects maintained a straight head position and turned their eyes to view off-axis targets. When necessary, the experimenter used a green laser pointer to guide the uncorrected fixation of the more highly myopic subjects.

The subject's accommodative response was also measured, both at far (4.0m) and near (33.0cm), with three measurements at each distance. Five measurements of axial

length, to the nearest 0.02mm, were taken on the right eye while subjects viewed a red fixation light.

Questionnaires

Subjects completed two questionnaires for the study, the Activities Questionnaire and the Clinical Data Questionnaire. The Activities Questionnaire (see Appendix 1), collected information about the subject's indoor and outdoor activities both currently and when the subject was 10 years old. The Activities Questionnaire was presented to subjects in four major parts, in random order: Winter Activities at 10 years old, Winter Activities at the current age, Summer Activities at 10 years old, and Summer Activities at the current age. Each of the four parts was further sub-divided into activities performed on an average weekday and those performed on an average weekend day. Activities for a given day were sectioned into those performed outdoors at distance, outdoors at near, indoors at distance, and indoors at near. Outdoor distance activities included: exercise/individual sports (e.g., running, biking, hiking), sports (e.g., hockey, football, basketball), driving (excluded from 10 year old questionnaire), outdoor leisure (e.g., picnic, spending time at the beach, leisure walking, hanging out with friends), outdoor work (e.g., construction, landscaping, mail carrier), and hunting/fishing. Outdoor near activities included: reading (e.g., reading for pleasure, studying), computer use/video games/text messaging, and hobbies/crafts. Indoor distance activities included exercise/individual sports and sports. Also included were indoor leisure (e.g., hanging out with friends), indoor work (e.g., cooking, cleaning), and time spent

watching TV/sitting in class/movie theater. Indoor near activities included the same entries and descriptors as outdoor near activities.

An 'other' entry was provided for each section, allowing the subjects to include activities which were not listed and/or for which they were unsure what category the activity would fit. Other questions from the Activities Questionnaire included sleeping and waking times at the current age in both winter and summer, on an average weekday and weekend day.

Questions from the Clinical Data Questionnaire included demographic information, location of birth, location of residence at 10 years of age and currently, sunglass usage at 10 years and currently, and age when the subject first started wearing optical correction (if applicable) (see Appendix 2).

Data Analysis

Refractive error

For all analyses the cohort (n= 59) was divided into two refractive groups, based upon SER: non-myopes (-0.49 D to +2.00 D) (n=21) and myopes (-0.50 D to -6.00 D) (n= 38).

Outdoor Activity

A subject's responses to the Activities Questionnaire were divided into 6 subcategories (as shown in Table 1) for each season (winter/summer), based on location (indoor/outdoor), type of activity (exercise/sports, leisure, work, etc.) and working distance

(distance/near): outdoor physical activity, outdoor leisure, outdoor near, indoor physical activity, indoor leisure, and indoor near. The 'other' category was excluded from further analysis, as it was rarely used; most subjects sought clarification during the study visit.

Table 1. Subcategories used in analysis of the Activities Questionnaire.

Activities Questionnaire Response Categories	Outdoor Physical Activity	Outdoor Leisure	Outdoor Near	Indoor Physical Activity	Indoor Leisure	Indoor Near
Outdoor Distance Activities						
Exercise/Individual Sports	x					
Sports	x					
Leisure Activities		x				
Outdoor Work	x					
Driving (current age only)		x				
Hunting/Fishing		x				
Outdoor Near Activities						
Reading			x			
Computer use/Video games/Text messaging			x			
Hobbies/Crafts			x			
Indoor Distance Activities						
Exercise/Individual Sports				x		
Sports				x		
Leisure Activities					x	
Indoor Work				x		
Watching TV/Sitting in class/Movie theater					x	
Indoor Near Activities						
Reading						x
Computer use/Video games/Text Messaging						x
Hobbies/Crafts						x

Each subject's hours of activity per week at their current age (including sleep) were calculated using a formula modified from that used in the Sydney Myopia Study (Rose et al., 2008, personal communication, 2012). Subjects reported their activity hours in one of four categories: 'not at all', 'less than 1 hour', '1 to 3 hours', 'more than 3 hours'. Each category was then assigned a numerical value as follows: 'not at all' = 0 hours, 'less than 1 hour' = 0.5 hours, '1 to 3 hours' = 1.5 hours, 'more than 3 hours' = 3 hours. The sum of all hours of activity and reported hours of sleep per night gave the daily hours of activity, for both a typical weekday and a typical weekend day. A subject's weekly activity hours were computed as the sum of 5 times the weekday activity hours plus 2 times the weekend day

hours. Given that performing tasks simultaneously was not taken into account, it was possible for subjects to report an excess of 24 hours of activity per day. In the following analyses all subjects with weekly activity hours in excess of 185.5, the equivalent of an average of 26.5 hours per day (including sleep), were eliminated from further analysis.

Weekly hours of activity were calculated in a similar fashion for the subjects' reported activities at 10 years of age. However, for these analyses sleep hours were not provided; therefore, 8 hours of sleep were assumed for all subjects.

Peripheral Refraction

Relative peripheral refractive error (RPRE) for each subject was calculated by subtracting the mean central SER at 2m from each retinal eccentricity (25˚ nasal and 25˚ temporal retina). For ease of interpretation, measured dioptric values for each refractive error group (myope/non-myope) were then normalized to 0.00 D, yielding relative peripheral refractive profiles. As an example, consider a myopic subject measuring -5.00 D centrally, -3.00 D nasally and -2.50 D temporally. When the central refractive error is normalized to 0.00 D (-5.00 D + 5.00 D = 0.00 D), the nasal and temporal refractive errors become +2.00 D (-3.00 D + 5.00 D = +2.00 D) and +2.50 D (-2.50 D + 5.00 D = +2.50 D), indicating the *relative difference* between the central and peripheral refractive errors, which in this case, is relative peripheral hyperopia.

Statistical Analyses

Descriptive statistics (means, standard deviations) were used to summarize the results. Due to the high correlation of refractive error between the two eyes (R= 0.98), only right eye data are presented and analyzed. To test for seasonal (winter vs. summer) activity differences within subjects, paired two sample t-tests were used. Two sample t-tests were used for comparisons across subjects (e.g., myope vs. non-myope). In cases of unequal variance between groups the two-sample t-test for unequal variance was applied. Relationships between variables were measured using Pearson correlation coefficients.

RESULTS

Table 2 shows mean central SER, mean age, and the gender distribution for all 59 study subjects, divided into those included in (n= 46) and excluded from (n= 13) the following analyses due to excessive numbers of weekly activity hours. As can be seen in the table, these values did not differ significantly between the included and excluded subjects.

Table 2. Mean central SER, age, and gender distribution of all subjects (n= 59), those included (n= 46) and those excluded (n= 13) from further data analysis.

	Subject Group			
	All Subjects (n=59)	Included in Data Analysis (n=46)	Excluded from Data Analysis (n=13)	P-value
mean SER (±SD) (D)	-1.43 (1.74)	-1.35 (1.75)	-1.73 (1.78)	0.78
mean age (± SD) (yrs)	24.02 (2.26)	24.15 (2.21)	23.54 (2.44)	0.69
male/female	26/33	20/26	6/7	0.99

As shown in Table 3, the mean central SER of the 46 subjects included in the data analyses was -1.35±1.75 D and their mean age was 24.15±2.21 years, with approximately equal numbers of males and females. The 46 subjects with data included in the analyses consisted of 28 myopes and 18 non-myopes. The mean SER for the myopic subjects was -2.47 ± 1.30 D and +0.39 ± 0.38 D for the non-myopic subjects ($p<0.01$). Overall, SER was highly correlated with axial length (R= -0.76). The two refractive groups had similar mean ages of 24 years ($p=0.71$) and gender distributions ($p=0.92$), with slightly more females in each group.

Table 3. Mean central SER, age, and gender distribution for subjects (n= 46) included in data analysis, separated by refractive error.

	Refractive Error Group			
	All Subjects (n=46)	Myopes (n=28) (-0.50D to -6.00D)	Non-Myopes (n=18) (-0.49D to +2.00D)	P-value
mean SER (±SD) (D)	-1.35 (1.75)	-2.47 (1.30)	+0.39 (0.38)	<0.01*
mean age (± SD) (yrs)	24.15 (2.21)	24.25 (2.46)	24.00 (1.81)	0.71
male/female	20/26	12/16	8/10	0.92

*Denotes significant result (i.e. $p\leq0.05$).

Activities Analysis – 10 years old

At 10 years of age, all subjects reported spending significantly less ($p<0.01$) total time outdoors in the winter than in the summer (mean= 19.24 hrs/wk in the winter vs. 38.53 hrs/wk in the summer) (Table 4a,b), and significantly ($p<0.01$) more total time indoors in the winter than the summer (63.38 hrs/wk in the winter vs. 47.92 hrs/wk in the summer) (Table 4c,d). Physical activity accounted for the majority of time spent outdoors during both

winter (10.51 hrs/wk) and summer (22.54 hrs/wk). A smaller portion of time was devoted to outdoor leisure activities or near activities. Unlike the outdoor activity results, for indoor activity time spent on physical activity was the smallest portion of total indoor time (12.58 hrs/wk in the winter; 8.15 hrs/wk in the summer). Most of the subjects' time was spent on indoor near activities (19.51 hrs/wk in the winter; 16.96 hrs/wk in the summer) or leisure activities (31.29 hrs/wk in the winter; 22.82 hrs/wk in the summer).

As shown in Table 4, at 10 years of age there were some statistically significant refractive group differences in activities. Myopic subjects reported spending significantly less total time outdoors than non-myopes during the winter (16.46±8.74 vs. 23.56±11.48 hrs/wk, respectively, $p=0.03$) and the summer (34.54±16.28 vs. 44.75±10.91 hrs/wk, respectively, $p=0.01$) (Table 4a,b). The overall result mainly reflects differences in hours of outdoor physical activity.

Table 4. Weekly activity hours for subjects at 10 years of age: (a) Winter Outdoor Activity, (b) Summer Outdoor Activity, (c) Winter Indoor Activity, (d) Summer Indoor Activity.

(a) Winter Outdoor Activity

	All Subjects (n=46)	**Myopes (n=28)**	**Non-Myopes (n=18)**	**P-value**
Outdoor Physical Activity	10.51 (6.15)	8.68 (5.26)	13.36 (6.49)	0.02*
Outdoor Leisure	6.33 (4.24)	6.48 (4.33)	6.08 (4.20)	0.76
Outdoor Near	2.40 (5.14)	1.30 (3.33)	4.11 (6.87)	0.07
Outdoor Total	**19.24 (10.38)**	**16.46 (8.74)**	**23.56 (11.48)**	**0.03***

(b) Summer Outdoor Activity

	All Subjects (n=46)	**Myopes (n=28)**	**Non-Myopes (n=18)**	**P-value**
Outdoor Physical Activity	22.54 (10.38)	19.11 (10.05)	27.89 (8.66)	<0.01*
Outdoor Leisure	11.09 (5.78)	11.27 (5.99)	10.81 (5.61)	0.79
Outdoor Near	4.90 (5.88)	4.16 (5.65)	6.06 (6.21)	0.29
Outdoor Total	**38.53 (15.15)**	**34.54 (16.28)**	**44.75 (10.91)**	**0.01***

(c) Winter Indoor Activity

	All Subjects (n=46)	**Myopes (n=28)**	**Non-Myopes (n=18)**	**P-value**
Indoor Physical Activity	12.58 (8.46)	10.79 (7.68)	15.36 (9.06)	0.07
Indoor Leisure	31.29 (9.73)	31.93 (9.45)	30.31 (10.35)	0.59
Indoor Near	19.51 (6.78)	20.39 (6.80)	18.14 (6.69)	0.28
Indoor Total	**63.38 (17.03)**	**63.11 (16.41)**	**63.81 (18.44)**	**0.89**

(d) Summer Indoor Activity

	All Subjects (n=46)	**Myopes (n=28)**	**Non-Myopes (n=18)**	**P-value**
Indoor Physical Activity	8.15 (6.77)	7.27 (5.84)	9.53 (7.99)	0.27
Indoor Leisure	22.82 (11.38)	23.54 (10.56)	21.69 (12.80)	0.60
Indoor Near	16.96 (8.22)	19.07 (8.07)	13.67 (7.51)	0.03*
Indoor Total	**47.92 (18.88)**	**49.88 (19.24)**	**44.89 (18.41)**	**0.39**

*Denotes significant result (i.e. $p \leq 0.05$).

Overall, subjects spent fewer hours in outdoor physical activity in the winter than the summer, and in each season myopes spent fewer hours outdoors than non-myopes. As shown in the left panel of Figure 2, during the winter myopes spent significantly fewer hours per week in outdoor physical activity than non-myopes (8.68 hrs/wk for myopes vs. 13.36 hrs/wk for non-myopes; $p=0.02$). In the summer myopes also spent significantly fewer weekly hours in outdoor physical activity than non-myopes (19.11 hrs/wk for myopes vs. 27.89 hrs/wk for non-myopes; $p<0.01$).

With respect to indoor activity there was only one statistically significant refractive group difference; myopic subjects reported spending significantly more time than non-myopes on indoor near activity in the summer (19.07±8.07 hrs/wk for myopes vs. 13.67±7.51 hrs/wk for non-myopes; $p=0.03$) (Table 4d). There was also a trend ($p=0.07$) for non-myopes to spend more time on indoor physical activity in the winter (Table 4c).

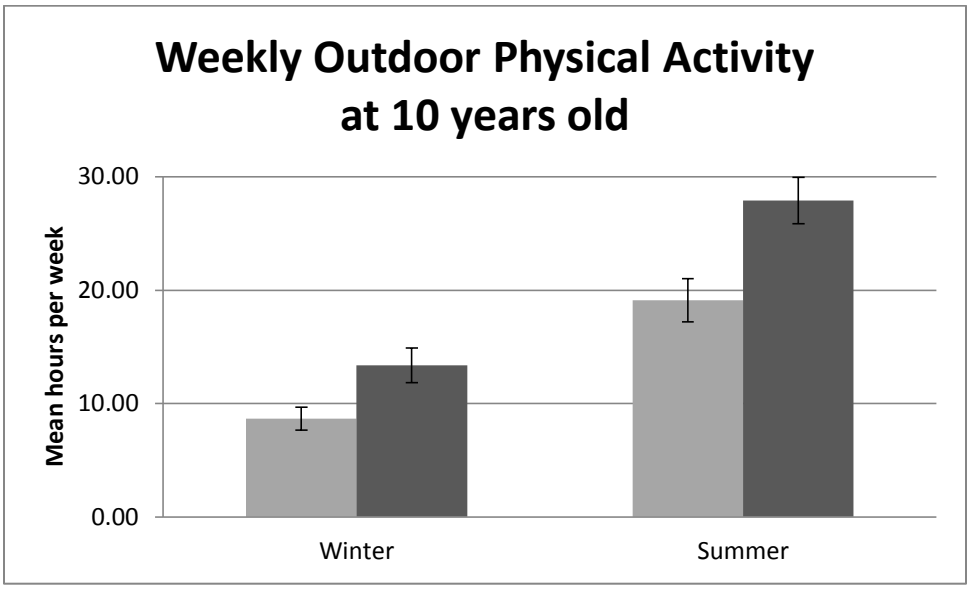


Figure 2. Comparison of weekly hours of outdoor physical activity between myopes (light grey) and non-myopes (dark grey), in both winter and summer, at 10 years old; significant results (i.e. $p \leq 0.05$) were seen during both seasons.

The differences observed in the myopic and non-myopic groups with respect to outdoor physical and indoor near activities raised the possibility of a substitution of hours of one activity for another. Figure 3a presents each subject's hours of outdoor physical activity in the winter plotted against their indoor near activity, while Figure 3b presents the same results during the summer. The weak correlations for all subjects (R= 0.16 for winter; R= -0.15 for summer) suggest that the results reported above are unlikely due to substitution of hours of one activity for another. A moderate correlation (R= 0.43) was found between outdoor physical and indoor near activities for the myopic subjects during the winter months, but it was positive not negative, providing additional evidence for the absence of a substitution effect.

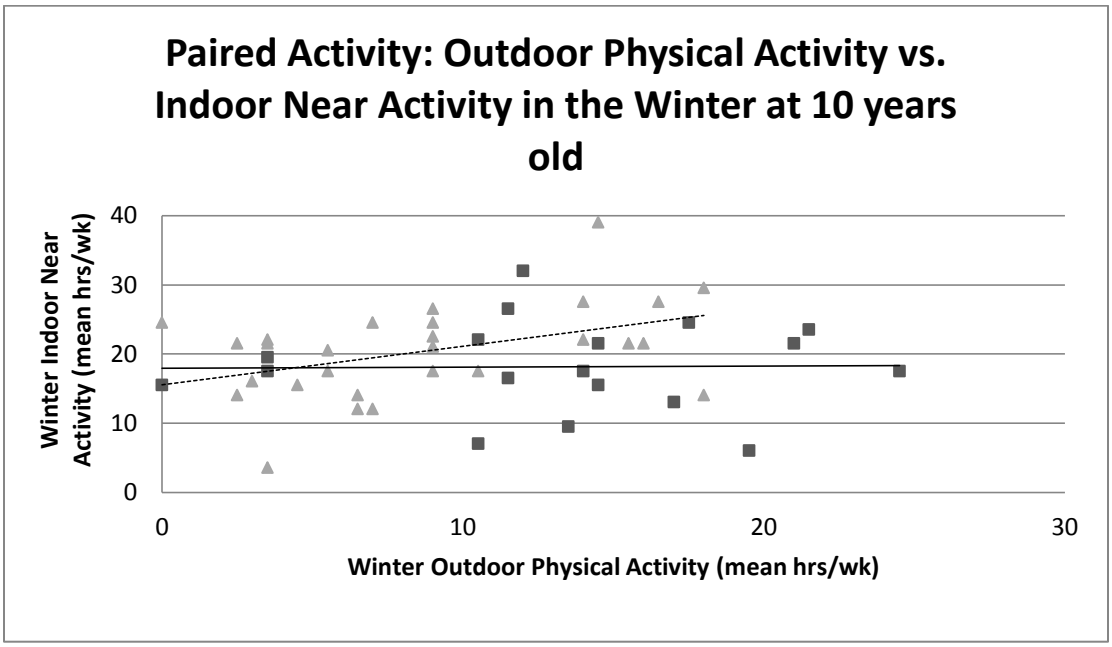


Figure 3a. Paired activity scatter plot: Winter outdoor physical activity vs. winter indoor near activity at 10 years old for myopes (n= 28, light grey triangles, dashed trendline) and non-myopes (n= 18, dark grey squares, solid trendline); R= 0.43 myopes, R= 0.02 non-myopes.

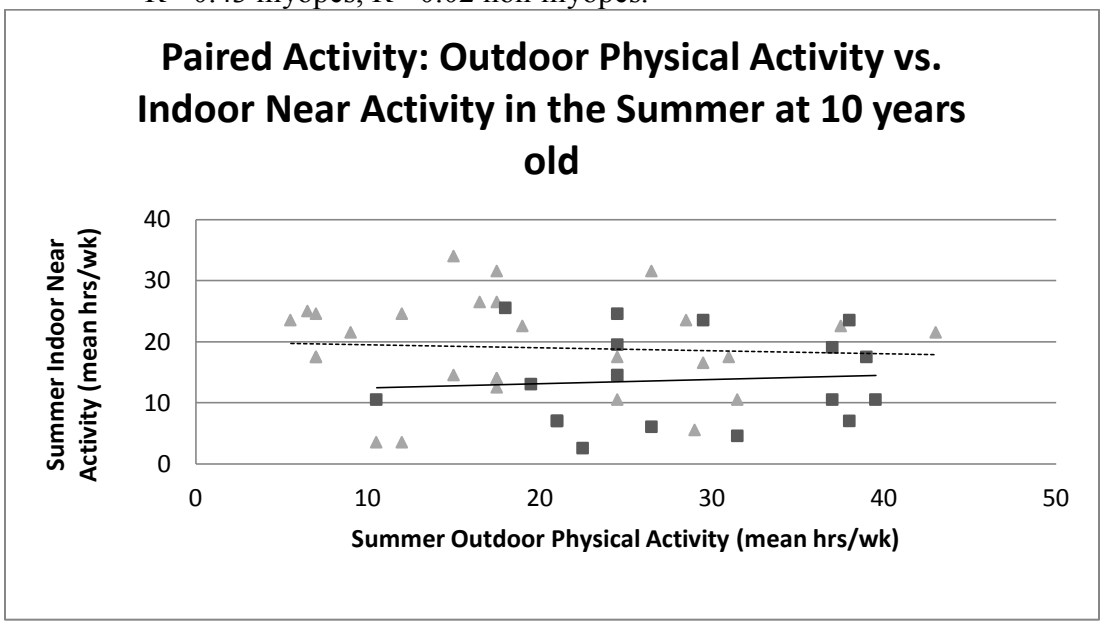


Figure 3b. Paired activity scatter plot: Summer outdoor physical activity vs. summer indoor near activity at 10 years old for myopes (n= 28, light grey triangles, dashed trendline) and non-myopes (n= 18, dark grey squares, solid trendline); R= -0.06 myopes, R= 0.08 non-myopes.

Activities Analysis – Current Age

All subjects reported spending fewer hours outdoors in the winter than in the summer at their current age (14.23 hrs/wk in the winter vs. 28.45 hrs/wk in the summer; $p<0.01$) (Table 5a,b). Subjects split time outdoors roughly equally between physical and leisure activities. This was evident during both seasons (5.21 vs. 6.24 hrs/wk in the winter; 11.33 vs. 11.98 hrs/wk in the summer, for outdoor physical and outdoor leisure activities, respectively). Not surprisingly, subjects spent significantly more time indoors in the winter than in the summer (64.23 hrs/wk in the winter vs. 49.17 hrs/wk in the summer; $p<0.01$) (Table 5c,d). Indoors, subjects spent the majority of their total time on leisure (22.97 hrs/wk in winter; 18.55 hrs/wk in summer) and near activities (27.16 hrs/wk in winter; 18.93 hrs/wk in summer), while physical activity occupied the least amount of time indoors in both the winter and summer.

At the current age only one significant refractive group difference was found, in winter outdoor leisure activities ($p=0.02$) (Table 5a). There was also a trend ($p=0.06$) towards non-myopic subjects spending more total time outdoors in the winter, driven by the difference in leisure activities. Unlike at age 10 years, at their current age myopes and non-myopes reported similar hours of outdoor physical activity during both the winter ($p=0.11$) and summer ($p=0.57$), as shown in the left and right panels of Figure 4, respectively. Subjects also reported similar total hours of indoor activity at their current age, regardless of season or refractive status (Table 5c,d), although non-myopes reported spending slightly more time than myopes being physically active indoors in the summer ($p=0.07$).

Table 5. Weekly activity hours for subjects at their current age: (a) Winter Outdoor Activity, (b) Summer Outdoor Activity, (c) Winter Indoor Activity, (d) Summer Indoor Activity.

(a) Winter Outdoor Activity at Current Age

	All Subjects (n=46)	**Myopes (n=28)**	**Non-Myopes (n=18)**	**P-value**
Outdoor Physical Activity	5.21 (4.90)	4.27 (3.10)	6.67 (6.68)	0.11
Outdoor Leisure	6.24 (5.33)	4.68 (4.60)	8.67 (5.60)	0.02*
Outdoor Near	2.78 (5.67)	2.79 (6.39)	2.78 (4.50)	0.99
Outdoor Total	**14.23 (11.12)**	**11.73 (9.41)**	**18.11 (12.66)**	**0.06**

(b) Summer Outdoor Activity at Current Age

	All Subjects (n=46)	**Myopes (n=28)**	**Non-Myopes (n=18)**	**P-value**
Outdoor Physical Activity	11.33 (7.83)	10.79 (7.74)	12.17 (8.11)	0.57
Outdoor Leisure	11.98 (6.19)	11.32 (5.46)	13.00 (7.23)	0.38
Outdoor Near	5.14 (5.52)	4.50 (5.44)	6.14 (5.65)	0.33
Outdoor Total	**28.45 (12.17)**	**26.61 (11.73)**	**31.31 (12.62)**	**0.20**

(c) Winter Indoor Activity at Current Age

	All Subjects (n=46)	**Myopes (n=28)**	**Non-Myopes (n=18)**	**P-value**
Indoor Physical Activity	14.10 (8.33)	12.80 (8.80)	16.11 (7.31)	0.19
Indoor Leisure	22.97 (8.06)	22.23 (7.86)	24.11 (8.47)	0.45
Indoor Near	27.16 (9.32)	28.30 (8.61)	25.39 (10.34)	0.31
Indoor Total	**64.23 (14.85)**	**63.34 (15.78)**	**65.61 (13.58)**	**0.62**

(d) Summer Indoor Activity at Current Age

	All Subjects (n=46)	**Myopes (n=28)**	**Non-Myopes (n=18)**	**P-value**
Indoor Physical Activity	11.68 (7.00)	10.18 (6.01)	14.03 (7.93)	0.07
Indoor Leisure	18.55 (9.23)	19.55 (10.09)	17.00 (7.73)	0.37
Indoor Near	18.93 (7.80)	19.38 (8.00)	18.25 (7.64)	0.64
Indoor Total	**49.17 (14.57)**	**49.11 (15.09)**	**49.28 (14.15)**	**0.97**

*Denotes significant result (i.e. $p \leq 0.05$).

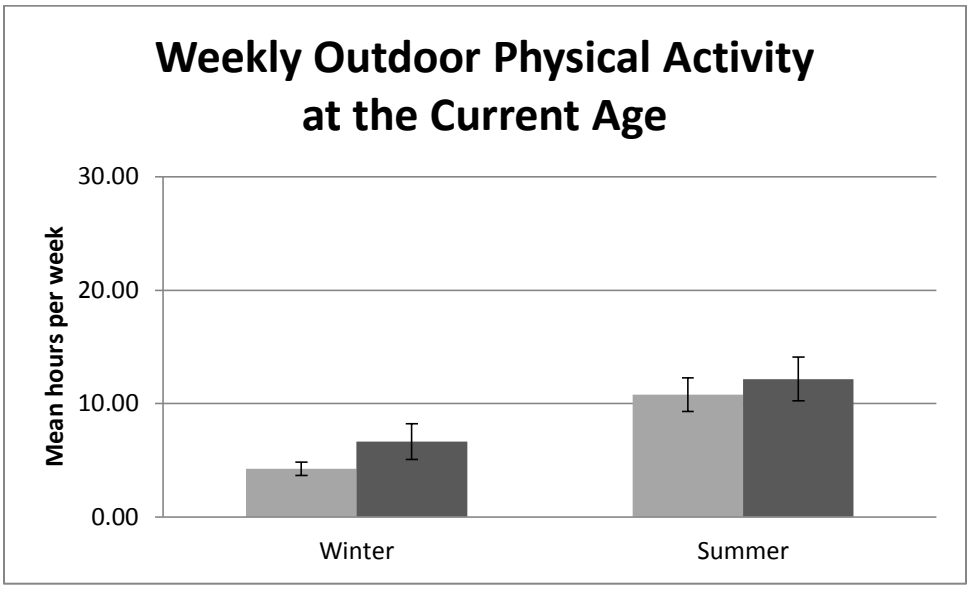


Figure 4. Comparison of weekly hours of outdoor physical activity between myopes (light grey) and non-myopes (dark grey), in both winter and summer, at their current age.

Activities Analysis – Comparison of 10 years old and current age

Total mean hours of outdoor activity were larger at 10 years than at the current age, in both the winter (19.24 hrs/wk for 10 years vs. 14.23 hrs/wk for current age, $p=0.01$) and the summer (38.53 hrs/wk for 10 years vs. 28.45 hrs/wk for current age; $p<0.01$). This difference was due mostly to subjects reporting approximately twice as many outdoor physical activity hours per week at 10 years than at their current age, in both winter (10.51 hrs/wk at 10 years old vs. 5.21 hrs/wk at current age; $p<0.01$) and summer (22.54 hrs/wk at 10 years old vs. 11.33 hrs/wk at current age; $p<0.01$). Subjects spent similar hours per week in leisure and near activities outdoors, regardless of season or age.

Total hours of indoor activity were similar between the two age groups ($p=0.72$ for winter; $p=0.62$ for summer); however, some seasonal and age differences were observed. Subjects at 10 years of age reported spending more time engaged in indoor leisure activity for both winter (31.29 hrs/wk at 10 years old vs. 22.97 hrs/wk at current age; $p<0.01$) and summer (22.82 hrs/wk at 10 years old vs. 18.55 hrs/wk at current age; $p=0.02$). Conversely, subjects reported more indoor physical and indoor near activities at their current age than when they were 10 years old, again for both seasons

Total hours of physical activity (hours of physical activity outdoors + hours of physical activity indoors) were found to be significantly different between myopes and non-myopes at 10 years of age, and borderline at the current age, as shown in Figures 5a and 5b. Non-myopic subjects spent significantly more time than myopic subjects being physically active in the winter at 10 years (28.72 vs. 19.46 hrs/wk; $p<0.01$); this trend was also found at the current age ($p=0.08$), as shown in the left and right panels of Figure 5a, respectively. As shown in Figure 5b, similar results were found during the summer months, with non-myopes spending more total hours in physical activity than myopes at 10 years (37.42 vs. 26.38 hrs/wk; $p<0.01$), with the findings borderline significant at the current age ($p=0.12$).

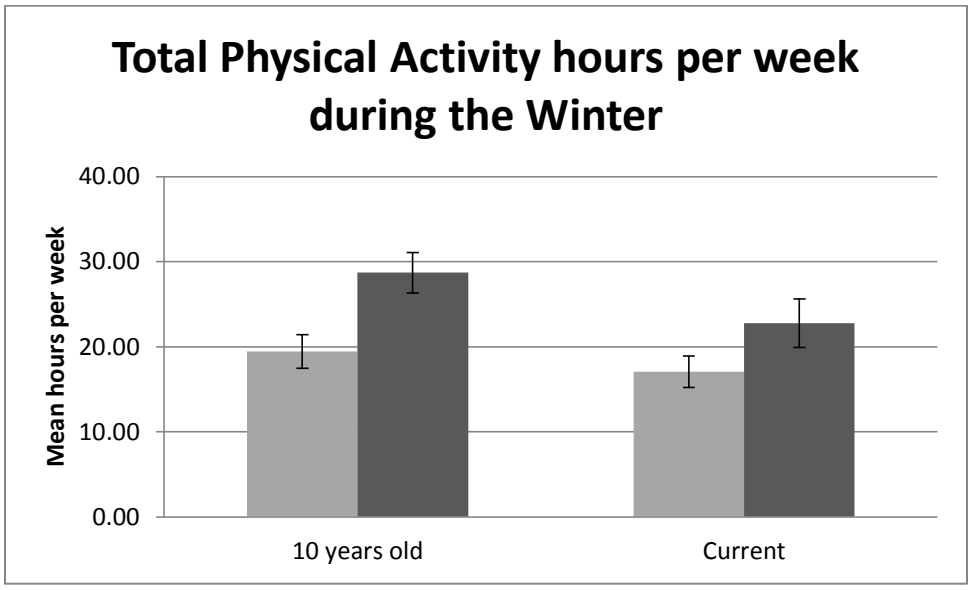


Figure 5a. Comparison of total weekly hours of physical activity between myopes (light grey) and non-myopes (dark grey), during the winter, at 10 years old and their current age. A significant result was observed between myopes and non-myopes at 10 years old.

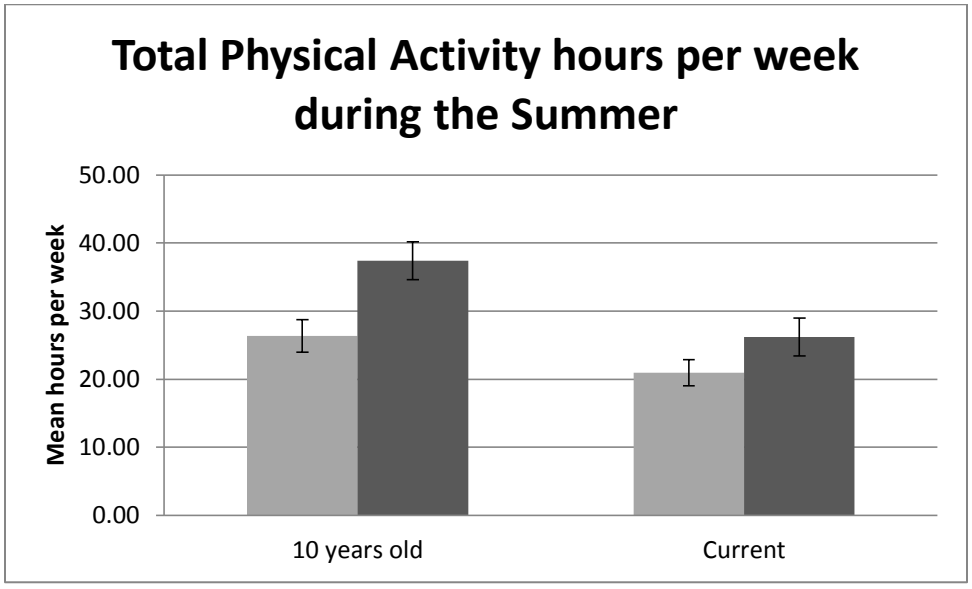


Figure 5b. Comparison of total weekly hours of physical activity between myopes (light grey) and non-myopes (dark grey), during the summer, at 10 years old and their current age. A significant result was observed between myopes and non-myopes at 10 years old.

Data were collected on the age of first ocular correction and accommodative response. Figure 6 presents each myopic subject's reported age of first correction plotted against their current refractive error. The moderate correlation (R= 0.47) shows that the more highly myopic subjects tended to be corrected at younger ages. In addition, 20 of 28 (71%) of the myopic subjects were first corrected after 10 years of age, suggesting that the onset of myopia was later than the activity hours reported by the subjects at 10 years of age. Accommodative response was weakly correlated with refractive error (R= 0.30), in the direction of reduced accommodation with more myopic/less hyperopic refractions.

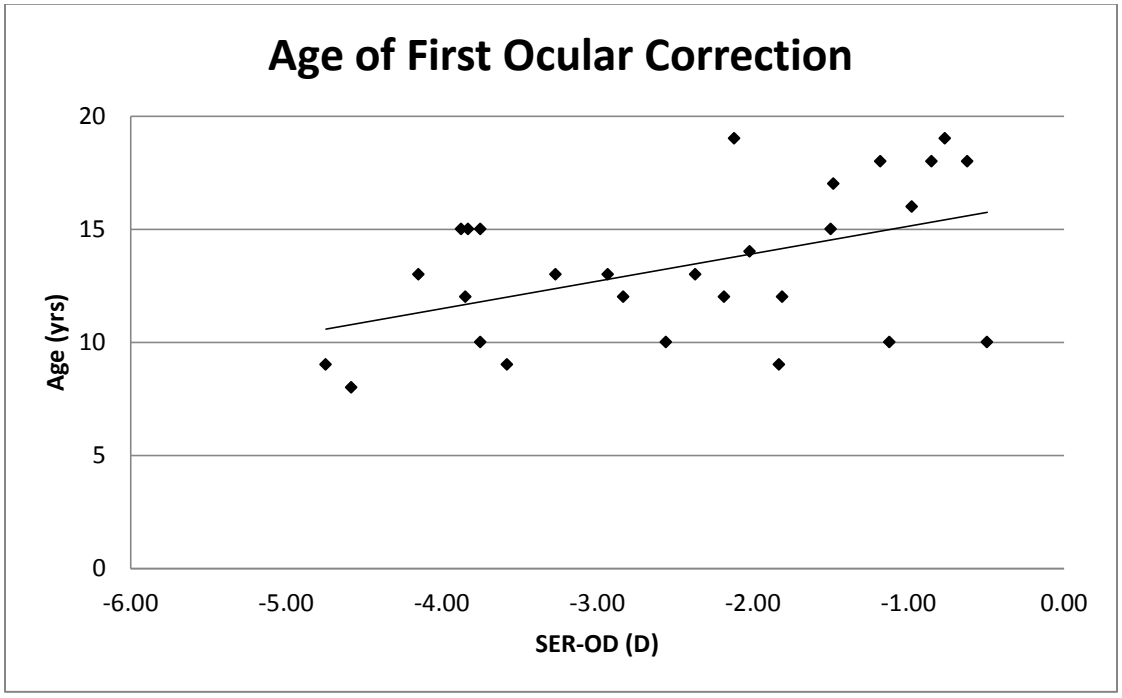


Figure 6. Age of first ocular correction vs. current refractive error of the myopic subjects (n=28); R= 0.47.

Peripheral Refraction

Measured (mean SER ± SD) peripheral refraction for all subjects, myopes and non-myopes is presented in Table 6. The mean central refractive error at 2m for all subjects was -1.52±1.71D, reflecting the 28 myopes in the study population. Looking at peripheral refraction by refractive group, myopic subjects had less myopia (relative peripheral hyperopia) both nasally and temporally. Non-myopic subjects were emmetropic in the nasal retina and displayed actual and relative peripheral myopia temporally. The marked nasal-temporal asymmetry found in the non-myopes was not seen in the myopes.

Table 6. Mean (±SD) measured peripheral refractive error, for all subjects, and by refractive error group.

	Measured Peripheral Refractive Error		
	25˚ Nasal Retina	Central	25˚ Temporal Retina
All Subjects (n=46)	-1.28 ± 1.81D	-1.52 ± 1.71D	-1.54 ± 1.39D
Myopes (n=28)	-2.31 ± 1.34D	-2.55 ± 1.29D	-2.21 ± 1.33D
Non-Myopes (n=18)	+0.45 ± 1.00D	+0.24 ± 0.32D	-0.41 ± 0.45D

Figure 7 presents the peripheral refractive profiles of myopes and non-myopes, with central refractive error normalized to 0.00 D for both groups, facilitating comparison of relative differences in the periphery. Both refractive groups showed similar small amounts of relative peripheral hyperopia in the nasal retina (+0.25 D for myopes, +0.21 D for non-myopes; p=0.90). However, in the temporal retina the mean refractions relative to the

central refractions were significantly different (+0.35D for myopes, -0.65D for non-myopes; $p<0.01$).

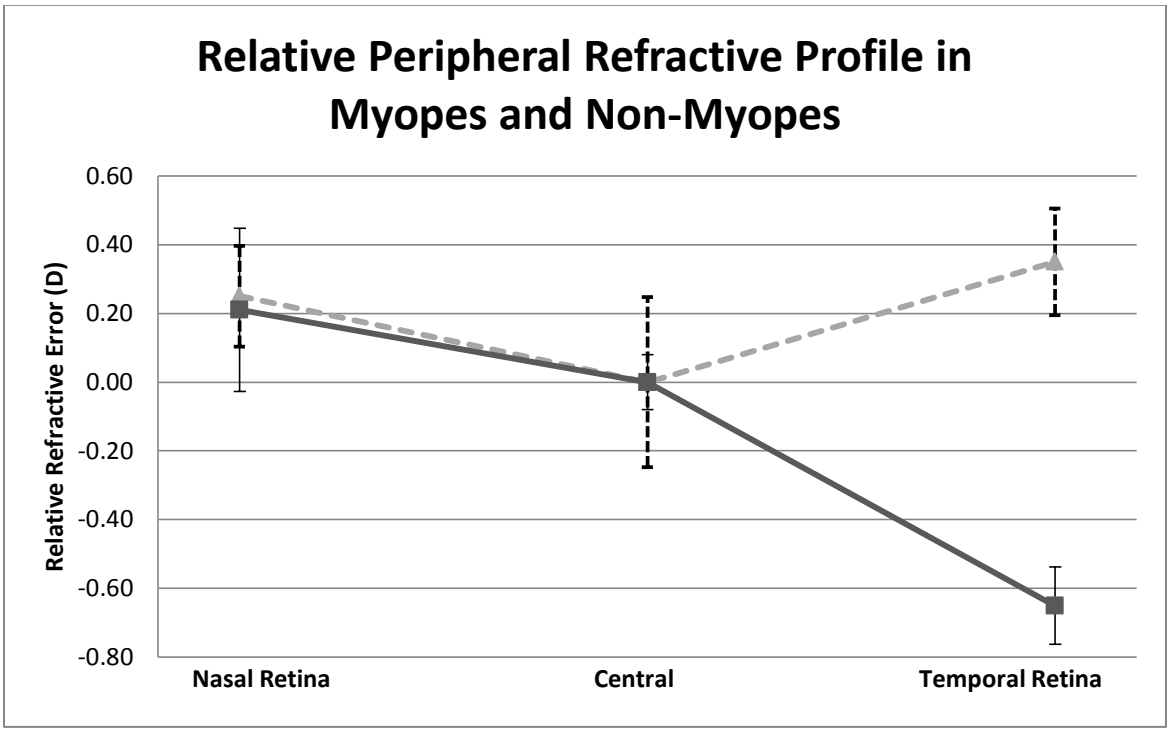


Figure 7. Relative peripheral refraction (with central measurements normalized to 0.00 D) of myopes (light grey triangles, dashed lines and dashed error bars) and non-myopes (dark grey squares, solid lines and solid error bars).

Relationship between Outdoor Activity and Peripheral Refraction

Although myopes were found to spend less time outdoors than non-myopes, and myopes were found to have more relative peripheral hyperopia than non-myopes in the temporal retina, less time outdoors was not correlated with peripheral refraction. Figure 8 shows data comparing the two factors. The most striking intergroup difference between refractive error and total hours of outdoor activity was observed in subjects at 10 years old during the summer (34.54 hrs/wk for myopes vs. 44.75 hrs/wk for non-myopes;

p=0.01; Table 4), and is presented in Figure 8, compared with the relative peripheral refractive error of each subject. As shown in Figure 8, non-myopes tended to have higher levels of outdoor activity and all non-myopic subjects had relative peripheral myopia in the temporal retina, denoted by negative dioptric values. Most myopic subjects showed relative peripheral hyperopia (positive dioptric values), while a few showed relative peripheral myopia. Overall, myopes had lower outdoor activity hours. However, no significant correlation between total outdoor activity hours and relative peripheral refractive error was seen in myopes (R= 0.13) or non-myopes (R= 0.08)

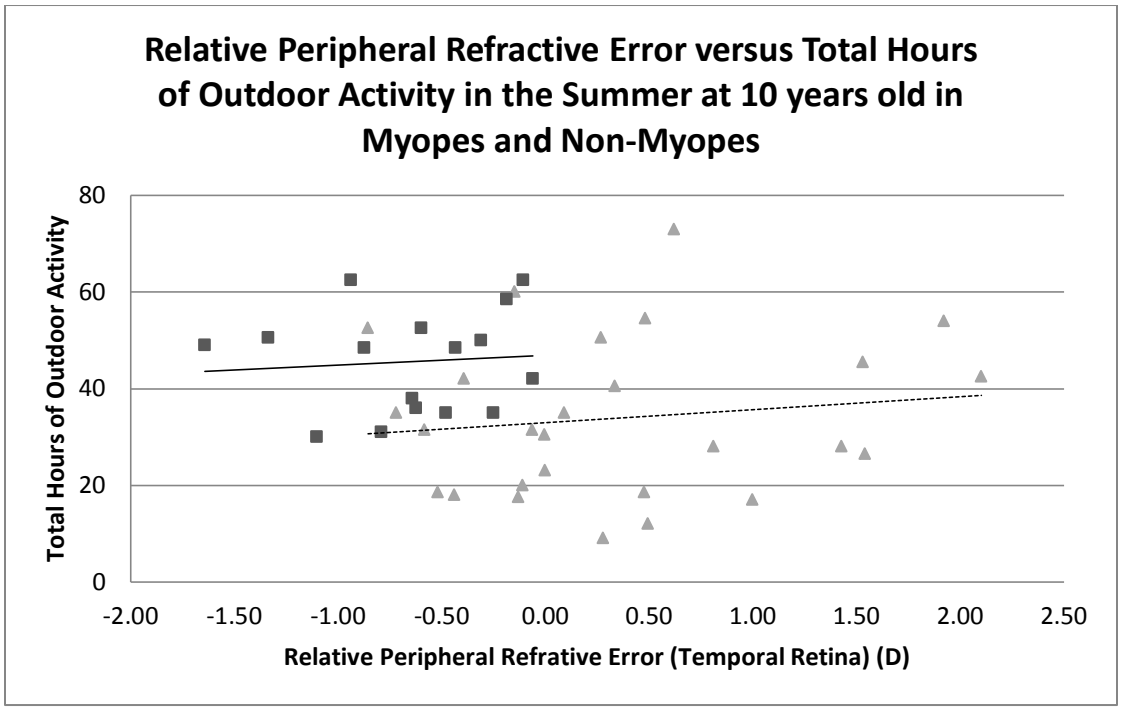


Figure 8. Relative peripheral refractive error (temporal retina) vs. total hours of summer outdoor activity at 10 years old, in myopes (light grey triangles, dashed line) and non-myopes (dark grey squares, solid line); negative dioptric values indicate relative peripheral myopia, positive values indicate relative peripheral hyperopia.

DISCUSSION

Outdoor Activity

Our study agrees with others in showing that reported hours of outdoor activity differ between myopes and non-myopes (Mutti et al., 2002, Jones et al., 2007, Rose et al., 2008, Deng et al., 2010, Jones-Jordan et al., 2011, Guggenheim et al., 2012, Sherwin et al., 2012, French et al., 2013). Unlike the other studies, we reported results on visual activities from two ages (10 years old and the participants' current age (mean= 24.15±2.21 years)) in the same set of subjects, and showed significant differences that may be relevant for myopigenesis. We found that myopes spent significantly less time outdoors than their non-myopic peers at 10 years old but not as young adults, during both winter and summer. Given that the average age of myopia onset is approximately 10 years old, the results from our myopic participants as children likely reflect activities that occurred before or at the age of onset. To address age of onset directly, we asked our subjects to report the age of first ocular correction. The majority of our subjects were first corrected after 10 years old, which implies that they developed myopia after that age. Those subjects who developed greater amounts of myopia tended to receive their first ocular correction at younger ages.

A trend was present for myopes being outdoors less than non-myopes at their current age; however, these results did not reach statistical significance. These findings are not unexpected, as myopia has generally stabilized by young adulthood and stable myopes are similar to emmetropes in many respects.

Given that we observed refractive group differences in visual activities at 10 years, and an association of ocular correction with age, our results suggest that the early pattern of behavior contributed to the later development of myopia.

Outdoor versus physical activity

In the literature there is little evidence as to whether the source of the protective effect is from being outdoors or being physically active. A primary aim of our study was to differentiate between time spent outdoors and in physical activity. Similar to our results for time spent outdoors, we noted differences in the level of physical activity between myopic and non-myopic subjects at 10 years old, but not at their current age. When they were 10 years old, myopes were significantly less physically active overall (outdoor physical activity + indoor physical activity) than non-myopes, again regardless of season. This finding was largely due to myopes spending significantly less time being physically active outdoors. Both refractive groups reported similar hours of indoor physical activity. The absence of a refractive group difference in indoor activity suggests that time outdoors is the main factor driving the differences and thus likely to be protective against myopia.

This conclusion agrees with that of Rose et al. (2008), who suggested that time outdoors, and not physical activity, is the protective factor against myopia development, based in part on finding no association between 'indoor sport' and refractive error, similar to our results. Using a different analytic approach, Guggenheim et al. (2012) found time outdoors to be protective against myopia development and also suggested that physical activity played a role, but less so than time outdoors. Using both univariate and multivariate

Cox regressions, Guggenheim et al. (2012) found lower hazard ratios (HR) in time outdoors (HR= 0.66-0.76) than in physical activity (HR= 0.85-0.87), for myopia developing after 11 years old. The hazard ratios presented for physical activity might also reflect time outdoors, as indoor and outdoor activities were not separated. Given that these ratios are higher (i.e. less protective) than those for being outdoors, the contributions of physical activity may be small.

The role of near work

Unlike outdoor activity, the role of near work in myopia development has been harder to determine based on questionnaire data (Jones et al., 2007, Ip et al., 2008, Rose et al., 2008, Deng et al., 2010). We found that myopes spent significantly more hours per week engaged in indoor near activities than non-myopes, during the summer months when they were 10 years old. Our results are in agreement with Deng et al. (2010), who reported that myopic children spent more time reading during the summer break, but not during the school year. This raises the possibility that myopes may have simply substituted hours spent outdoors for hours indoors. However, we found no significant negative correlations between outdoor physical activity and indoor near work during either season at either age. Our results parallel those of Rose et al. (2008), Mutti et al. (2002), and Deng et al. (2010), who also found no substitution effect. The fact that we found significant refractive group differences in outdoor and indoor activity when the data were analyzed categorically, but not continuously, is not surprising given that these two methods of analysis can produce different results. In addition, the data analyses may not have accounted for all the activities occurring in a 24-hour day.

Seasonal differences in activity and myopia progression

Like Guggenheim et al. (2012) and Deng et al. (2010), we observed distinct differences in the winter/summer activity patterns of our subjects, important information when considering the role of outdoor activity and near work on myopia development and progression. Myopia has been shown to progress more during the winter than the summer months, which likely reflects a combination of more time in school and less time outdoors in the winter (Gwiazda et al., ARVO 2012; Donovan, Sankaridurg, Ho, Chen, Lin, Thomas, Smith, Ge, and Holden, 2012; Fulk and Cyert, 1996; Fulk, Cyert, and Parker, 2002; Goss and Rainey, 1998). We found that all subjects, regardless of refractive error, reported an increase in outdoor activity hours between the winter and summer months. We also found that subjects decreased their indoor activity hours between the winter and summer months. Our findings are analogous to Deng et al. (2010), where children spent significantly more time studying during the school year (similar to our winter months) and in outdoor activity in the summer. While not all of our subjects lived in the vicinity of Boston, Massachusetts when they were 10 years old, 85% of them lived in areas with distinct seasons when they were children, similar to the climate in New England. All of them also went to school in the winter and had summer vacations. Taken together, these results suggest that the different seasonal patterns of activity likely contribute to the development and progression of myopia.

Possible mechanisms

The literature agrees that the biological mechanisms involved in the development and progression of myopia are multi-faceted, involving both genetic and environmental elements. However, the exact nature of these mechanisms remains unknown. Our data show that being outdoors is related to refractive error.

Most animal studies point to light as a key factor. Investigations in multiple animal species have found the presence of high ambient light levels (both natural and artificial) to slow eye growth in form-deprivation myopia (Ashby et al., 2009, Smith et al., 2012), indicating a mechanism driven by light intensity. Possible explanations for these observations include the role of light in pupillary constriction, where a smaller pupil will increase the depth of focus and decrease image blur, impeding growth signals. Neuromodulator release has also been shown to contribute to the protective effects of light. It is known that dopamine is a powerful growth inhibitor, which is released in response to light absorption by light-sensitive amacrine cells. In addition, dopamine antagonists have been shown to interfere with the recovery of form-deprivation myopia (McCarthy, Megaw, Devadas, and Morgan, 2007). A role for cutaneous Vitamin D has also been proposed, though the evidence thus far is not compelling (Mutti and Marks, 2011b).

While most of the literature using animal models supports a strong role for light intensity, a recent study in monkeys found that high light levels did not protect against negative-lens-induced myopia, in contrast to form-deprivation myopia (Smith et al., 2013). Given that negative-lens-induced myopia is more relevant to human myopia, this recent result means that factors in addition to light need to be considered.

In addition to this recent finding from monkeys, other studies testing humans also suggest that light cannot be the only factor. This is supported by the finding of seasonal differences in myopia progression, observed in vastly different geographical areas and latitudes, as mentioned above. If light were the only factor, one would not expect to find the same seasonal differences in myopia progression in areas with very different seasonal light/dark cycles, for example, the northern United States (Goss and Rainey, 1998) and southern China (Donovan et al., 2012).

One possible factor is distance viewing during outdoor activities, where minimal demand is placed on the accommodative system. This induces myopic defocus, which has been shown to slow axial elongation in animals (reviewed by Flitcroft, 2012)). Another possibility is the role of hyperopic defocus during near work, which has been shown to induce axial elongation in animal models (reviewed by Flitcroft, 2012). Flitcroft recently has incorporated these factors and others into a comprehensive theory of myopigenesis.

Peripheral refraction

As a secondary analysis, we explored what, if any, association might be present between outdoor activity and relative peripheral refractive error because myopes and non-myopes have different peripheral refractive profiles, as reviewed by Charman and Radhakrishnan (2010).

Our peripheral refraction results showed refractive group differences, but only in the temporal retina, where myopes tended to have mild relative hyperopia and non-myopes had marked relative myopia. In the nasal retina the mean refraction was relative hyperopia for

both refractive groups. Because we only measured peripheral refraction when our subjects were young adults with established refractive errors, we cannot say what their peripheral refractive profiles showed as children. However, hints come from two recent studies in children (Mutti et al., 2011a, Sng et al., 2011) that reported finding relative peripheral hyperopia only after myopia developed. When we compared relative peripheral refractive error at the current age to the level of outdoor activity at 10 years old, no significant associations were found. Given that relative peripheral hyperopia has been shown to not be predictive of later myopia (Mutti et al., 2011a, Sng et al., 2011), these results are not surprising.

Strengths and limitations

To our knowledge, this is the first study to investigate outdoor activities at two time points in the same group of subjects, including both young adulthood and (retrospectively) childhood. Another strength of our study was the separation of time outdoors from physical activity, as well as division of activity levels by season. This questionnaire construction and analysis method allowed us to gather a more complete picture of our subjects' behavior than a questionnaire with a single age, season or activity description.

Inherent to the use of questionnaires, recall bias on the part of the subjects is a possibility. However, the fact that our results are similar to other published studies surveying subjects via questionnaire suggests that our data were not strongly influenced by recall bias. This observation is supported by French et al. (2013), where 12 year olds tested at baseline and 6 year olds who completed a 6 year follow-up questionnaire at 12 years old gave similar

responses. Additionally, it is possible that the results were influenced by a small sample size and a sample of convenience due to the subject population being comprised largely of optometry students. However, our study showed some highly significant refractive group differences and it is also likely that our subjects correctly remembered certain aspects of their history (e.g., age of ocular correction).

Conclusions

In conclusion, myopic individuals spent less time outdoors as children than their non-myopic peers, during both the winter and summer months, but young adults had similar activity levels, regardless of refractive error or season. Our data suggest that during the period of rapid myopia progression, children who are outdoors more often, and who engage in fewer hours of indoor near work during the winter and summer, might develop less myopia. These data further suggest that being physically active is not the main source of the protective effects. Measuring and/or correcting peripheral refraction in children is not likely to be helpful in slowing myopia progression. Overall, the main clinical recommendation emerging from these results is to send children outdoors as often as possible.

REFERENCES

Ashby, R., Ohlendorf, A., & Schaeffel, F. (2009). The effect of ambient illuminance on the development of deprivation myopia in chicks. *Investigative Ophthalmology & Visual Science*, 50(11): 5348-5354.

Charman, W.N., & Radhakrishnan, H. (2010). Peripheral refraction and the development of refractive error: a review. *Ophthalmic and Physiological Optics*, 30(4): 321-338.

Deng, L., Gwiazda, J., & Thorn, F. (2010). Children's refractions and visual activities in the school year and summer. *Optometry and Vision Science*, 87(6): 406-413.

Dirani, M., Tong, L., Gazzard, G., Zhang, X., Chia, A., Young, T.L., Rose, K.A., Mitchell, P., & Saw, S.M. (2009). Outdoor activity and myopia in Singapore teenage children. *British Journal of Ophthalmology*, 93(8): 997-1000.

Donovan, L., Sankaridurg, P., Ho, A., Chen, X., Lin, Z., Thomas, V., Smith, E.L., 3rd, Ge, J., & Holden, B. (2012). Myopia progression in Chinese children is slower in summer than in winter. *Optometry and Vision Science*, 89(8): 1196-1202.

Flitcroft, D.I. (2012). The complex interactions of retinal, optical and environmental factors in myopia aetiology. *Progress in Retinal and Eye Research*, 31(6): 622-660.

French, A.N., Morgan, I.G., Mitchell, P., & Rose, K.A. (2013). Patterns of myopigenic activities with age, gender and ethnicity in Sydney schoolchildren. *Ophthalmic and Physiological Optics*, doi: 10.1111/opo.12045. [Epub ahead of print].

Fulk, G.W., & Cyert, L.A. (1996). Can bifocals slow myopia progression? *Journal of the American Optometric Association*, 67(12): 749-754.

Fulk, G.W., Cyert, L.A., & Parker, D.A. (2002). Seasonal variation in myopia progression and ocular elongation. *Optometry and Vision Science*, 79(1): 46-51.

Goss, D.A., & Rainey, B.B. (1998). Relation of childhood myopia progression rates to time of year. *Journal of the American Optometric Association*, 69(4): 262-266.

Guggenheim, J.A., Northstone, K., McMahon, G., Ness, A.R., Deere, K., Mattocks, C., Pourcain, B.S., & Williams, C. (2012). Time outdoors and physical activity as predictors of incident myopia in childhood: a prospective cohort study. *Investigative Ophthalmology & Visual Science*, 53(6): 2856-2865.

Hoogerheide, J., Rempt, F., & Hoogenboom, W.P. (1971). Acquired myopia in young pilots. *Ophthalmologica*, 163(4): 209-215.

Ip, J.M., Saw, S.M., Rose, K.A., Morgan, I.G., Kifley, A., Wang, J.J., & Mitchell, P. (2008). Role of near work in myopia: findings in a sample of Australian school children. *Investigative Ophthalmology & Visual Science*, 49(7): 2903-2910.

Jacobsen, N., Jensen, H., & Goldschmidt, E. (2008). Does the level of physical activity in university students influence the development and progression of myopia?--a 2-year prospective cohort study. *Investigative Ophthalmology & Visual Science*, 49(4): 1322-1327.

Jones, L.A., Sinnott, L.T., Mutti, D.O., Mitchell, G.L., Moeschberger, M.L., & Zadnik, K. (2007). Parental history of myopia, sports and outdoor activities, and future myopia. *Investigative Ophthalmology & Visual Science*, 48(8): 3524-3532.

Jones-Jordan, L.A., Mitchell, G.L., Cotter, S.A., Kleinstein, R.N., Manny, R.E., Mutti, D.O., Twelker, J.D., Sims, J.R., & Zadnik, K. (2011). Visual activity before and after the onset of juvenile myopia. *Investigative Ophthalmology & Visual Science*, 52(3): 1841-1850.

McCarthy, C.S., Megaw, P., Devadas, M., & Morgan, I.G. (2007). Dopaminergic agents affect the ability of brief periods of normal vision to prevent form-deprivation myopia. *Experimental Eye Research*, 84(1): 100-107.

Mutti, D.O., Mitchell, G.L., Moeschberger, M.L., Jones, L.A., & Zadnik, K. (2002). Parental myopia, near work, school achievement, and children's refractive error. *Investigative Ophthalmology & Visual Science*, 43(12): 3633-3640.

Mutti, D.O., Sinnott, L.T., Mitchell, G.L., Jones-Jordan, L.A., Moeschberger, M.L., Cotter, S.A., Kleinstein, R.N., Manny, R.E., Twelker, J.D., & Zadnik, K; CLEERE Study Group. (2011a). Relative peripheral refractive error and the risk of onset and progression of myopia in children. *Investigative Ophthalmology & Visual Science*, 52(1): 199-205.

Mutti, D.O., & Marks, A.R. (2011b). Blood levels of vitamin D in teens and young adults with myopia. *Optometry and Vision Science*, 88(3): 377-382.

Pacella, R., McLellan, J., Grice, K., Del Bono, E.A., Wiggs, J.L., & Gwiazda, J.E. (1999). Role of genetic factors in the etiology of juvenile-onset myopia based on a longitudinal study of refractive error. *Optometry and Vision Science*, 76(6): 381-386.

Quek, T.P., Chau, C.G., Chong, C.S., Chong, J.H., Hey, H.W., Lee, J., Lim, Y.F., & Saw, S.M. (2004). Prevalence of refractive errors in teenage high school students in Singapore. *Ophthalmic and Physiological Optics*, 24(1): 47-55.

Rose, K.A., Morgan, I.G., Ip, J., Kifley, A., Huynh, S., Smith, W., & Mitchell, P. (2008). Outdoor activity reduces the prevalence of myopia in children. *Ophthalmology*, 115(8): 1279-1285.

Rosén, R., Lundström, L., Unsbo, P., & Atchison, D.A. (2012). Have we misinterpreted the study of Hoogerheide et al. (1971)? *Optometry and Visual Science*, 89(8): 1235-1237.

Saw, S.M., Chua, W.H., Hong, C.Y., Wu, H.M., Chan, W.Y., Chia, K.S., Stone, R.A., & Tan, D. (2002). Nearwork in early-onset myopia. *Investigative Ophthalmology & Visual Science*, 43(2): 332-339.

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Saw, S.M., Gazzard, G., Shih-Yen, E.C., & Chua, W.H. (2005). Myopia and associated pathological complications. *Ophthalmic and Physiological Optics*, 25(5): 381-391.

Sherwin, J.C., Reacher, M.H., Koegh, R.H., Khawaja, A.P., Mackey, D.A., & Foster, P.J. (2012). The association between time spent outdoors and myopia in children and adolescents: a systematic review and meta-analysis. *Ophthalmology*, 119(10): 2141-2151.

Smith, E.L., 3rd, Ramamirtham, R., Qiao-Grider, Y., Hung, L.F., Huang, J., Kee, C.S., Coats, D., Paysse, E. (2007). Effects of foveal ablation on emmetropization and form-deprivation myopia. *Investigative Ophthalmology & Visual Science*, 48(9): 3914-3922.

Smith, E.L., 3rd, Hung, L.F., Huang, J. (2009). Relative peripheral hyperopic defocus alters central refractive development in infant monkeys. *Vision Research*, 49(19): 2386-2392.

Smith, E.L., 3rd, Hung, L.F., Huang, J. (2012). Protective effects of high ambient lighting on the development of form-deprivation myopia in rhesus monkeys. *Investigative Ophthalmology & Visual Science*, 53(1): 421-428.

Smith, E.L., 3rd, Hung, L.F., Arumugam, B., Huang, J. (2013). Negative-lens-induced myopia in infant monkeys: Effects of high ambient lighting. *Investigative Ophthalmology & Visual Science*, doi:pii: iovs.13-11713v1. 10.1167/iovs.13-11713. [Epub ahead of print].

Sng, C.C., Lin, X.Y., Gazzard, G., Chang, B., Dirani, M., Lim, L., Selvaraj, P., Ian, K., Drobe, B., Wong, T.Y., & Saw, S.M. (2011). Change in peripheral refraction over time in Singapore Chinese children. *Investigative Opthalmology & Visual Science*, 52(11): 7880-7887.

Vitale, S., Sperduto, R.D., & Ferris, F.L., 3rd. (2009). Increased prevalence of myopia in the United States between 1971-1972 and 1999-2004. *Archives of Ophthalmology*, 127(12): 1632-1639.

Williams, C., Miller, L.L., Gazzard, G., & Saw, S.M. (2008). A comparison of measures of reading and intelligence as risk factors for the development of myopia in a UK cohort of children. *British Journal of Ophthalmology*, 92(8): 1117-1121.

Appendix 1:

Activities Questionnaire

Study No. _____

****10 YEAR OLD****
WINTER ACTIVITIES QUESTIONNAIRE

Introduction to questions
We are interested in learning whether there might be a relationship between the amount of time people spend engaged in different outdoor and indoor activities and refractive error.

INSTRUCTIONS FOR COMPLETION
Study participants are asked to please answer each of the following questions with the response that best corresponds to the amount of time spent engaged in each activity. Responses should indicate the time you spent on a typical **winter** weekday or weekend day **when you were 10 years old.**

Please include the hours throughout the entire day instead of just after school.

Additional instructions are:

1. Each specific activity is to be checked for 1 category only (for example, guitar playing should not be considered under hobbies, and then again specified under "other").
2. **It is important that all items are completed.** If the "other" category is not applicable, then "not at all" should be checked.
3. If "other" is checked for a particular category, responses should include the total amount of time spent in all "other" activities.
4. Responses should cover all activities conducted during a given day
5. **The total number of hours used for different activities should not exceed 24 hours for a typical day.**

I. Please respond for a *Typical WINTER WEEKDAY* (Mon-Fri) when you were 10 years old

Outdoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating, hiking, rollerblading)				
Sports (e.g., basketball, football, baseball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., BBQs, picnic, beach, leisure walking, school or daycare recess, playing with friends*)*				
Outdoor work (e.g., delivering newspapers, helping with yard work)				
Hunting, fishing				
Other, please describe:				
Outdoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., school homework, reading for pleasure)				
Computer use/video games				
Hobbies, crafts (e.g., drawing, writing)				
Other, please describe:				
Indoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**>3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating)				
Sports (e.g., basketball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., playing with friends, school or daycare indoor recess*)*				
Indoor work (e.g., chores, helping prepare meals)				
Watching TV, videos, DVDs				
Movie Theater/Sitting in class at school				
Other, please describe:				
Indoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., school homework, reading for pleasure)				
Computer use/Video games				
Hobbies, crafts (e.g., drawing, writing)				
Other, please describe:				

II. Please respond for a *Typical WINTER WEEKEND DAY* (Sat-Sun) when you were 10 years old

Outdoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating, hiking, rollerblading)				
Sports (e.g., basketball, football, baseball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., BBQs, picnic, beach, leisure walking, school or daycare recess, playing with friends*)*				
Outdoor work (e.g., delivering newspapers, helping with yard work)				
Hunting, fishing				
Other, please describe:				
Outdoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., school homework, reading for pleasure)				
Computer use/video games				
Hobbies, crafts (e.g., drawing, writing)				
Other, please describe:				
Indoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**>3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating)				
Sports (e.g., basketball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., school or daycare indoor recess, playing with friends*)*				
Indoor work (e.g., chores, helping prepare meals)				
Watching TV, videos, DVDs				
Movie Theater/Sitting in class at school				
Other, please describe:				
Indoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., school homework, reading for pleasure)				
Computer use/Video games				
Hobbies, crafts (e.g., drawing, writing)				
Other, please describe:				

Study No. _____

****10 YEAR OLD****
SUMMER ACTIVITIES QUESTIONNAIRE

Introduction to questions
We are interested in learning whether there might be a relationship between the amount of time people spend engaged in different outdoor and indoor activities and refractive error.

INSTRUCTIONS FOR COMPLETION
Study participants are asked to please answer each of the following questions with the response that best corresponds to the amount of time spent engaged in each activity. Responses should indicate the time you spent on a typical **summer** weekday or weekend day **when you were 10 years old.**

Please include the hours throughout the entire day instead of just after school.

Additional instructions are:

1. Each specific activity is to be checked for 1 category only (for example, guitar playing should not be considered under hobbies, and then again specified under "other").
2. **It is important that all items are completed.** If the "other" category is not applicable, then "not at all" should be checked.
3. If "other" is checked for a particular category, responses should include the total amount of time spent in all "other" activities.
4. Responses should cover all activities conducted during a given day
5. **The total number of hours used for different activities should not exceed 24 hours for a typical day.**

I. Please respond for a *Typical SUMMER WEEKDAY* (Mon-Fri) when you were 10 years old

Outdoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating, hiking, rollerblading)				
Sports (e.g., basketball, football, baseball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., BBQs, picnic, beach, leisure walking, school or daycare recess, playing with friends*)*				
Outdoor work (e.g., delivering newspapers, helping with yard work)				
Hunting, fishing				
Other, please describe:				
Outdoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., school homework, reading for pleasure)				
Computer use/video games				
Hobbies, crafts (e.g., drawing, writing)				
Other, please describe:				
Indoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**>3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating)				
Sports (e.g., basketball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., playing with friends, school or daycare indoor recess*)*				
Indoor work (e.g., chores, helping prepare meals)				
Watching TV, videos, DVDs				
Movie Theater/Sitting in class at school				
Other, please describe:				
Indoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., school homework, reading for pleasure)				
Computer use/Video games				
Hobbies, crafts (e.g., drawing, writing)				
Other, please describe:				

II. Please respond for a *Typical SUMMER WEEKEND DAY* (Sat-Sun) when you were 10 years old

Outdoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating, hiking, rollerblading)				
Sports (e.g., basketball, football, baseball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., BBQs, picnic, beach, leisure walking, school or daycare recess, playing with friends*)*				
Outdoor work (e.g., delivering newspapers, helping with yard work)				
Hunting, fishing				
Other, please describe:				
Outdoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., school homework, reading for pleasure)				
Computer use/video games				
Hobbies, crafts (e.g., drawing, writing)				
Other, please describe:				
Indoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**>3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating)				
Sports (e.g., basketball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., school or daycare indoor recess, playing with friends*)*				
Indoor work (e.g., chores, helping prepare meals)				
Watching TV, videos, DVDs				
Movie Theater/Sitting in class at school				
Other, please describe:				
Indoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., school homework, reading for pleasure)				
Computer use/Video games				
Hobbies, crafts (e.g., drawing, writing)				
Other, please describe:				

Study No. _____

****CURRENT AGE****
WINTER ACTIVITIES QUESTIONNAIRE

Introduction to questions
We are interested in learning whether there might be a relationship between the amount of time people spend engaged in different outdoor and indoor activities and refractive error.

INSTRUCTIONS FOR COMPLETION
Study participants are asked to please answer each of the following questions with the response that best corresponds to the amount of time spent engaged in each activity. Responses should indicate the time you **currently** spend on a typical **winter** weekday or weekend day.

Please include the hours throughout the entire day instead of just after school or work.

Additional instructions are:

1. Each specific activity is to be checked for 1 category only (for example, guitar playing should not be considered under hobbies, and then again specified under "other").
2. **It is important that all items are completed.** If the "other" category is not applicable, then "not at all" should be checked.
3. If "other" is checked for a particular category, responses should include the total amount of time spent in all "other" activities.
4. Responses should cover all activities conducted during a given day
5. **The total number of hours used for different activities should not exceed 24 hours for a typical day.**

I. Please respond for a *Typical WINTER WEEKDAY* (Mon-Fri) currently

Outdoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating, hiking, rollerblading)				
Sports (e.g., basketball, football, baseball, volleyball, hockey, tennis)				
Driving				
Leisure activities *(*e.g., BBQs, picnic, beach, leisure walking, hanging out with friends*)*				
Outdoor work (e.g., construction, mail carrier, landscaping, yard work)				
Hunting, fishing				
Other, please describe:				
Outdoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., studying, reading for pleasure)				
Computer use/video games, text messaging				
Hobbies, crafts (e.g., sketching, knitting)				
Other, please describe:				
Indoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**>3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating)				
Sports (e.g., basketball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., hanging out with friends*)*				
Indoor work (e.g., cooking, cleaning)				
Watching TV/Sitting in class				
Movie Theater				
Other, please describe:				
Indoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., studying, reading for pleasure)				
Computer use/Video games, text messaging				
Hobbies, crafts (e.g., sketching, knitting)				
Other, please describe:				

II. Please respond for a *Typical WINTER WEEKEND DAY* (Sat-Sun) currently

Outdoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating, hiking, rollerblading)				
Sports (e.g., basketball, football, baseball, volleyball, hockey, tennis)				
Driving				
Leisure activities *(*e.g., BBQs, picnic, beach, leisure walking, hanging out with friends*)*				
Outdoor work (e.g., construction, mail carrier, landscaping, yard work)				
Hunting, fishing				
Other, please describe:				
Outdoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., studying, reading for pleasure)				
Computer use/video games, text messaging				
Hobbies, crafts (e.g., sketching, knitting)				
Other, please describe:				
Indoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**>3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating)				
Sports (e.g., basketball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., hanging out with friends*)*				
Indoor work (e.g., cooking, cleaning)				
Watching TV/Sitting in class				
Movie Theater				
Other, please describe:				
Indoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., studying, reading for pleasure)				
Computer use/Video games, text messaging				
Hobbies, crafts (e.g., sketching, knitting)				
Other, please describe:				

IV. Additional Questions

Currently, what time do you usually go to sleep and what time do you usually get up?

Typical WINTER WEEKDAY (Mon-Fri):

Go to sleep at: _ _: _ _ **(hr./ min)** AM PM (Please check one only)

Get up at: _ _: _ _ **(hr./ min)** AM PM (Please check one only)

Typical WINTER WEEKEND DAY (Sat-Sun):

Go to sleep at: _ _: _ _ **(hr./ min)** AM PM (Please check one only)

Get up at: _ _: _ _ **(hr./ min)** AM PM (Please check one only)

Study No. _____

****CURRENT AGE****
SUMMER ACTIVITIES QUESTIONNAIRE

Introduction to questions
We are interested in learning whether there might be a relationship between the amount of time people spend engaged in different outdoor and indoor activities and refractive error.

INSTRUCTIONS FOR COMPLETION
Study participants are asked to please answer each of the following questions with the response that best corresponds to the amount of time spent engaged in each activity. Responses should indicate the time you **currently** spend on a typical **summer** weekday or weekend day.

Please include the hours throughout the entire day instead of just after school or work.

Additional instructions are:

1. Each specific activity is to be checked for 1 category only (for example, guitar playing should not be considered under hobbies, and then again specified under "other").
2. **It is important that all items are completed.** If the "other" category is not applicable, then "not at all" should be checked.
3. If "other" is checked for a particular category, responses should include the total amount of time spent in all "other" activities.
4. Responses should cover all activities conducted during a given day
5. **The total number of hours used for different activities should not exceed 24 hours for a typical day.**

I. Please respond for a *Typical SUMMER WEEKDAY* (Mon-Fri) currently

Outdoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating, hiking, rollerblading)				
Sports (e.g., basketball, football, baseball, volleyball, hockey, tennis)				
Driving				
Leisure activities *(*e.g., BBQs, picnic, beach, leisure walking, hanging out with friends*)*				
Outdoor work (e.g., construction, mail carrier, landscaping, yard work)				
Hunting, fishing				
Other, please describe:				
Outdoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., studying, reading for pleasure)				
Computer use/video games, text messaging				
Hobbies, crafts (e.g., sketching, knitting)				
Other, please describe:				
Indoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**>3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating)				
Sports (e.g., basketball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., hanging out with friends*)*				
Indoor work (e.g., cooking, cleaning)				
Watching TV/Sitting in class				
Movie Theater				
Other, please describe:				
Indoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., studying, reading for pleasure)				
Computer use/Video games, text messaging				
Hobbies, crafts (e.g., sketching, knitting)				
Other, please describe:				

II. Please respond for a *Typical SUMMER WEEKEND DAY* (Sat-Sun) currently

Outdoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating, hiking, rollerblading)				
Sports (e.g., basketball, football, baseball, volleyball, hockey, tennis)				
Driving				
Leisure activities *(*e.g., BBQs, picnic, beach, leisure walking, hanging out with friends*)*				
Outdoor work (e.g., construction, mail carrier, landscaping, yard work)				
Hunting, fishing				
Other, please describe:				
Outdoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., studying, reading for pleasure)				
Computer use/video games, text messaging				
Hobbies, crafts (e.g., sketching, knitting)				
Other, please describe:				
Indoor Distance Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**>3 Hours**
Exercise/individual sports activities (e.g., walking, running, biking, skating)				
Sports (e.g., basketball, volleyball, hockey, tennis)				
Leisure activities *(*e.g., hanging out with friends*)*				
Indoor work (e.g., cooking, cleaning)				
Watching TV/Sitting in class				
Movie Theater				
Other, please describe:				
Indoor Near Activities	**Not at All**	**< 1 Hour**	**1-3 Hours**	**> 3 Hours**
Reading (e.g., studying, reading for pleasure)				
Computer use/Video games, text messaging				
Hobbies, crafts (e.g., sketching, knitting)				
Other, please describe below:				

III. Additional Questions

A) When reading or studying (in print or online), how frequently do you usually take a break or look up?

(Please choose one (best) response only)

1 at least every 15 minutes?

2 at least every 30 minutes?

3 at least every 45 minutes?

4 at least once every hour?

5 less often than once every hour?

B) **Currently**, what time do you usually go to sleep and what time do you usually get up?

Typical SUMMER WEEKDAY (Mon-Fri):

Go to sleep at: _ _: _ _ **(hr./ min)** AM PM (Please check one only)

Get up at: _ _: _ _ **(hr./ min)** AM PM (Please check one only)

Typical SUMMER WEEKEND DAY (Sat-Sun):

Go to sleep at: _ _: _ _ **(hr./ min)** AM PM (Please check one only)

Get up at: _ _: _ _ **(hr./ min)** AM PM (Please check one only)

Appendix 2:

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 history.

Today's 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)
Place of Birth Please specify the locality, region (if applicable) and nation of your birth Ex. Steubenville, Ohio, United States Dholka, Gujarat, India	_____
Gender (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 **b.** Are you of Hispanic or Latino descent? (Yes/No)	**a.** _____ **b.** _____

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. **b.** Do you utilize prescription birth control (Ex. 'the pill' or 'the patch'? (Yes/No) **c.** Have you ever suffered a serious injury or illness? If so, please specify the approximate date(s) and nature of the incident(s).	**a.** _____ **b.** _____ **c.** _____ _____ _____
Ophthalmic History **a.** Do you use corrective eyewear such as glasses or contact lenses? (Yes/No) i. If so, when did you first start wearing your corrective eyewear? (Year/Age) ii. If so, are you nearsighted (have trouble seeing far away) or farsighted (have trouble seeing up close)? (Please circle one) **b.** Do you wear contact lenses? (Yes/No) i. If so, are your contacts considered 'extended wear'? (Yes/No) **c.** Have you ever been told you have a lazy eye, eye turn or squint? (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 one of the examples below)	**a.** _____ **i.** _____ Year Age **ii.** Nearsighted Farsighted **b.** _____ **i.** _____ **c.** _____ **d.**

Ex. Right Eye **(OD)** -6.75 +0.25 X 96 Left Eye **(OS)** +2.25 -0.75 X 180 **e.** Have you ever had Corneal Refractive Therapy (CRT) or Orthokeratology (Ortho-K)? (Yes/No) **f.** Have you ever had Laser Assisted In Situ Keratomileusis (LASIK) or Photorefractive Keratectomy (PRK)? (Yes/No) **Ophthalmic History (continued)** **g.** Do you regularly use eye drops? (Yes/No) **h.** Have you ever sustained an injury to either eye? (Yes/No) i. If so, for each injury please specify <u>which eye</u> and the nature and date of the injury.	**OD** _____ **OS** _____ **e.** _____ **f.** _____ **g.** _____ **h.** _____ **i.** _____ _____ _____
Additional Notes Are there additional considerations of which you thing we should be aware? If so, please describe as succinctly as possible.	_____ _____ _____ _____