Continuous Objective Assessment of Near Work, Light Exposure, and Activity

By

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A thesis submitted to the Graduate Faculty,

College of Optometry

In partial fulfillment of the requirements for the degree of

Master of Sciences

In

Physiological Optics

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May 2020

Dedication

To my family, for their constant encouragement to pursue my dreams with excellence. To my parents, thank you for setting an example of working hard, as for the Lord, not for man. To my brothers, thank you for believing in me and being my greatest fans. To my grandparents, thank you for feeding me joy and perspective, even on my most challenging days.

To God, who supplied me this passion for optometry and vision science while in high school, and who has abundantly given the patience, joy, support, and resources in order to complete my education. Thank you for faithfully laying each stone before me, on which to take my next step in life, always with perfect timing. Thank you for being my hope and my salvation.

Acknowledgements

I would first like to thank my principal investigator, research mentor, and life mentor, Dr. Lisa Ostrin, for her abundant help in developing and completing my master's project. She coached me while making career decisions. She also served as a humble, ambitious, and successful researcher and professor from which to learn. Dr. Ostrin is a positive presence within the lab, always sharing new ideas with excitement. She is an incredibly fun mother of four, while holding countless leadership roles within the area of vision science research. She is a pioneer for women in research, and I could not have asked for a better mentor and role model.

Thank you to my fellow lab mates, including: Ashutosh Jnawali, Krista Beach, Hannah Burfield, Suyash Bakshi, and Ralphie Tran for their assistance in my project and providing inspiration through their own great research.

This project would not be possible without my thesis committee members, Dr. Kathryn Richdale and Dr. Eric Ritchey, who have provided me with insight far beyond my own. It has been a great honor to have such renown researchers in the field of myopia serve on my committee.

Lastly, I would like to extend my thanks to the faculty and staff at the University of Houston College of Optometry. It has been such a joy walking into the college every day for the past four years. The professors provide patient guidance and top tier optometric education. The staff offer never-ending support and every resource a student could need. I will forever be grateful for this school, it's ability to supply me with both a Doctorate and Master's degree, and providing a firm foundation upon which to build my continuing education as a PhD student.

Abstract

Purpose: Myopia, or nearsightedness, is an epidemic, with up to 90% of the population in urbanized countries affected. Myopia brings with it potentially blinding complications and significant socio-economic burden. Light exposure and near work are known risk factors for myopia. However, evidence regarding the role of near work in myopia is conflicting. Current technology allows for objective measurements of light exposure; however, quantification of near work is assessed via questionnaires, which are subject to poor recall, response, and parent biases. The purpose of this study was to introduce the RangeLife, a novel, custom device developed for continuous, objective measurement of near work. Further, the objective near work output was compared to traditional visual activity questionnaires and activity logs.

Methods: We developed the RangeLife, a device for continuous, objective measurement of working distance. Four devices were built, calibrated, and validated. Then, adult subjects wore the device on weekdays and weekend days, while simultaneously wearing an actigraph device for objective measurements of light exposure and activity. Subjects maintained an activity log and answered a visual activity questionnaire. RangeLife data were downloaded and binned into 0.10 m intervals. Objective diopter hours (dh), a weighted measure of near work, were calculated and compared with subjective diopter hours obtained from the questionnaire.

Results: Diopter hours for all subjects were significantly higher on weekdays (14.73 ± 4.67 dh) compared to weekends (11.90 ± 4.84 dh, $p = 0.05$). 94 ± 1.85% of near and intermediate viewing distances were recorded when the subjects were exposed to mesopic and indoor photopic light levels (<1000 lux), and 80.03 ± 2.11% during periods of sedentary physical activity (<320 counts per minute). Subjective reports of time viewing near and intermediate distances significantly overestimated objective measures ($p = 0.002$).

Conclusions: The RangeLife was shown to provide reliable measures of viewing distance, and can be further utilized to understand potential influences of viewing behaviors on refractive error.

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Chapter 1.

Introduction

1.1 Introduction of Myopia

1.1.1 Prevalence

Myopia, or nearsightedness, occurs when the eye fails to grow, or emmetropize, accurately. As a result, the length of the eye is too long for the focal power of its refractive elements. This produces blurry distance vision that requires correction in the form of spectacles, contact lenses, or surgery.[1] Myopia is not commonly found at birth, but increases in prevalence during school-aged years.[1] This condition affects approximately 40% of young adults in the United States[2] and nearly 90% of young adults in South East Asia.[3] Myopia, therefore, is an epidemic and the prevalence is increasing with each generation. It has been predicted that the global percentage of myopic individuals will rise to 49.8% of the world's population, with 9.8% having high myopia.[4] Myopia brings with it a significant socio-economic burden. A recent study assessed the potential productivity loss associated with uncorrected myopia and myopic macular degeneration, estimating the loss in the United States amounted to $250 billion in 2015 alone.[5] Given the increasing prevalence, significant socio-economic burden, and blinding comorbidities of myopia, research interests aim to determine the etiology and best preventative measures for helping to reduce onset and slow myopia progression.

1.1.2 Clinical Manifestations

Myopia is associated with numerous sight-threatening pathologies, including: retinal detachment,[6] macular degeneration,[7] cataract,[8] and glaucoma.[9] High myopia is generally defined as a refractive error $\geq$ -6 diopters (D).[10] Although any degree of myopia is a risk factor for ocular complications, those with high myopia are at a greater risk of having retinal complications due to the retinal stretching[11] and thinning[12] that accompany excessive axial elongation. These retinal conditions include posterior staphyloma, subretinal choroidal neovascularization, peripheral retinal thinning, lattice degeneration, and rhegmatogenous retinal detachment.[13] In addition, reports have shown patients with high myopia may have decreases in visual acuity,[14] contrast sensitivity,[15] and visual field sensitivity.[16] The rapidly increasing prevalence of myopia brings with it an increase in these vision threatening ocular conditions. This affects health care costs, economic productivity, and quality of life.

1.1.3 Pathophysiology

Myopia most often results from an axial length that is longer than the eye's focal power, defined as axial myopia. Myopia can also result from an overly steep cornea or a lens having increased power, called refractive myopia.[10] A myopic refractive error is rare among newborns and young children. The majority of newborns have a hyperopic refractive error.[17] During eye development in early childhood years, the process of emmetropization occurs. Emmetropization is when the eye's axial length increases in order to match the retina with image location in an unaccommodated eye.[18,19] Animal models have shown that emmetropization is guided by visual stimuli during development; however, eyes may continue to lengthen due to genetic and environmental factors.[20,21] Despite the rapidly growing prevalence of myopia, the epidemiology and pathophysiology are poorly understood. Efforts have increased to understand the regulatory mechanisms underlying myopia. These mechanisms of refractive development are regulated by a complex interaction between genetic, environmental, and behavioral factors.[20,21]

1.2 Refractive Development

1.2.1 Genetic Factors

Family history of myopia is associated with the likelihood of developing the condition. A greater prevalence of myopia exists among the children of myopic parents than among the children of non myopic parents. [22-25] Zadnik, *et al.*, showed that even before the onset of juvenile myopia, children of two myopic parents have longer eyes than children with one myopic parent or no myopic parents.[22] In addition, there is evidence that the ocular components and refractive errors of monozygotic twins are more closely aligned than they are for dizygotic twins, suggesting a genetic component.[26] Studies have shown that inter-sibling correlations are stronger than parent-offspring correlations in regards to developing myopia. It has been theorized that siblings share a common environment, whereas their parents may have grown up with different environmental exposures.[20] As a result, it is unknown to what extent these familial patterns are due to genetic or environmental factors. The large increase in myopia prevalence in certain parts of the world is at a rate incompatible with rates of change in gene pools. Therefore, although there are clear patterns of family inheritance and high heritability values, Rose *et al.*, has shown that high heritability does not preclude strong environmental influences.[20]

1.2.2 Influence of Light Exposure

Environmental factors are increasingly important in determining myopic outcomes, as shown by the rapid rate of change in the prevalence of myopia in urbanized countries.[2,27,28] Sunlight exposure has shown a convincing protective effect against myopia onset. In animal studies, Wang *et al.*, demonstrated with Rhesus monkeys that exposure to 3 hours of sunlight daily both prevents onset of myopia and reduces myopia that results from hyperopic defocus.[29]

In humans, studies looking at family history of myopia and time outdoors have shown that reduced time outdoors/physical activity increased the odds of children becoming myopic when they have two myopic parents more than when they have one or zero myopic parents.[30] In the Avon Longitudinal Study of Parents and Children (ALSPAC), they found that time spent outdoors was predictive of incident myopia in children independently of physical activity.[31] The Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) Study found that children who became myopic had fewer outdoor/sports activity hours than emmetropes before, at, and after myopia onset. In contrast, they found that near work activities did not differ between emmetropes and future myopic children. These results argue against a causative role for near work, and for a causative role for outdoor/sports activity in myopia onset.[32]

1.2.3 Influence of Near Work

"Near work" is considered activities performed at a close working distance, such as reading, writing, studying, painting, and looking at a computer, phone, or tablet. Some studies comparing populations have demonstrated an association between near work and myopia prevalence.[33-35] Several studies comparing myopia prevalence in rural and urban areas have found that there are a significantly greater amount of myopic children in urban areas.[36-38] One study suggested that this occurs due to urban children spending more time reading and writing than rural children.[38] However, in studies comparing individuals within a population, near work and myopia prevalence are weakly correlated.[30,39,40] As shown in the CLEERE Study, near work exposure and myopia prevalence have shown conflicting results.[32] These weak correlations may have resulted from absence of objective data, for each of these studies used subjective methods for quantifying near work which presents many limitations in quantifying near work, as discussed below.

Besides the amount of near work, relevant viewing behaviors that may affect eye growth include the duration of near viewing sessions, intermittent breaks during near viewing, and absolute viewing distance.[41] Using questionnaires to quantify near work distance and duration, Ip, *et al.* found that close reading distance (<30cm) and continuous reading (>30min) independently increased the odds of having myopia in a sample of 12 year old children.[39] In addition, animal studies using chicks,[42-44] tree shrews,[45-46] and rhesus monkeys[47-48] have demonstrated that defocused vision presented for multiple, interrupted time periods results in lower amounts of myopia than defocused vision presented continuously. These findings suggest that breaks while performing near work may be effective in slowing myopia progression.

1.3 Data Measurement

1.3.1 Questionnaires

Studies that evaluate near work in children have traditionally gathered subjective data through parent questionnaires. A questionnaire developed for the Sydney Myopia Study has been used frequently in research. This questionnaire examines the relationship between myopia and potential modifiable risk factors by surveying parents about their child's demographics, ocular family history, near work duration and behavior, light exposure, activity duration, sleep duration, and other potential influencing factors.[49] Questionnaires are typically easy to administer, cost-effective, have a high response rate, and are quick to complete.[50] However, questionnaires are often subject to poor recall bias.[51,52] In addition, questionnaires completed by parents can be subject to parent bias. In studies investigating differences between child and parent responses, findings showed that parents have little or false knowledge about their child's behavior in some cases.[53-59] For example, a parent may have a incorrect perceptions of how much time is spent performing near work or physical activity while their child is at school. For this reason, other subjective measures of near work have been implemented.

1.3.2 Diaries & Journals

The use of diaries and journals require subjects to record their activities and/or near work distance throughout the day. This method results in less recall bias, and therefore, more accurate data.[60] One study compared responses from a questionnaire and four 24-hour diaries, and found the two methods to be reproducible and comparable.[60] However, diaries only represent one day within a specific season of life, and may not represent accurately the behaviors of an individual. In addition, diaries are limited by subject compliance throughout the entire day. In order to improve compliance, other methods of data collection have been introduced.

1.3.3 Experience Sampling Method

The Experience Sampling Method is a technique utilized in research that acquires random samples of a subject's activity throughout the day. Subjects have a pager that receives alerts randomly throughout the day. Following each alert, subjects record their current activity and near work distance. This method allows for data collection without greatly affecting a subject's daily activities.[61-64] In several studies using the Experience Sampling Method, near work activity was captured with similarity to activity questionnaires completed by the subjects. However, in the Experience Sampling Method, only discreet time points are sampled, and the results are dependent on the subjects' response rate.[64] Ultimately, an objective and continuous method of data collection is necessary to provide the most accurate quantification of near work.

1.3.4 Objective Measurement of Light Exposure and Activity

Due to poor subject response, recall bias, and parent bias, objective measurements are the preferred method for obtaining data within scientific research. Studies implementing objective methods have shown discrepancies between objective and subjective data. For example, Alvarez and Wildsoet used a wearable sensor to objectively measure light exposure in young adults, while requiring the subjects to also complete a subjective questionnaire. Their results found poor agreement between the two methods of measurement.[65] Ostrin, *et al.* used an electronic wrist-worn device, the Actiwatch, to measure light, activity, and sleep in children and adults, and found that objective data compared with traditional subjective reports revealed significant differences. The results also provided objective evidence that light exposure was related to time of year, and that myopic children tended to spend less time outdoors in the summer than emmetropic children.[66] A later research study using the same electronic wearable device showed similar behaviors between children and their parents, suggesting that a household has similar environmental exposures.[67] Limitations for using the Actiwatch include a potential for poor subject compliance, accidental covering of the device with clothing, and a discrepancy between light intensity at eye versus wrist level.[67] As these devices become more available, cost-effective, and easy to use, efforts should be made to increase the use of objective measurements. These methods can improve the accuracy of data collection in studies determining myopia epidemiology.

1.3.5 Objective Measurements of Near Work

Near work has traditionally been assessed using subjective methods, such as questionnaires, diaries, and journals.[49,60] These methods rely on recall and individual assessments of working distance and duration. They also provide little information in regards to viewing behavior. One study used a range finding device that gathered continuous working distance data in high and low myopes. Using the objective device data and self-reported reading distances, the results demonstrated a significant difference in objective versus subjective outputs. The study did not, however, investigate working distance data during a subject's typical day to day behavior outside of the lab; the study only reported on two 10 minute experimental periods for each subject.[68] Therefore, there is a need for a method of assessing near work that is objective, continuous, has a high temporal resolution, and does not interfere with a subject's daily activities. This method of assessment is imperative to understanding the environmental and behavioral influences on eye growth.

1.4 Specific Aims

1.4.1 Novel Device for Objective Measurement

The first aim of this study was to develop a device for continuous, objective measurement of working distance. The field is lacking in objective information about time spent viewing various working distances, including near reading distance, intermediate computer distance, TV viewing distance and outdoor viewing distance. Subjective reports show that teens spend up to 8 hours performing near work on computers per day.[69] Viewing behavior may be an important factor in how near work might affect eye growth, e.g. whether subjects take breaks from near viewing by intermittently incorporating distance viewing during near wok. This factor can only be assessed with objective and continuous measurements of working distance, and it is imperative to our long-term goal of understanding the environmental and behavioral influences on eye growth.

In this study, the RangeLife devices were designed and built for continuous measurement of working distance. They were validated and calibrated, then utilized to assess near work in adults.

1.4.2 Objective Measurement of Near Work, Light Exposure, and Activity

The second aim was to collect daily near work data in adults and to compare objective working distance data with objective data of light exposure and physical activity. Studies with subjective questionnaire data have shown a significant association between myopia prevalence and time spent outdoors.[5,70,71] More recently, studies using objective data from light sensors have demonstrated that there are differences between subjective questionnaire data and objective measures of time outdoors[72] and that myopic children exhibit a significantly lower amount of outdoor light exposure compared to emmetropic children.[73] Use of wearable electronic monitoring devices, now available for quantifying light exposure, time spent outdoors, and activity, provides the opportunity to objectively and precisely quantify light levels and time spent outdoors, and correlate ambient illumination with activity levels.

In this study, a wearable electronic device was worn at the same time as the RangeLife device so that the factors of light exposure, activity, and sleep could be correlated with viewing distance.

1.4.3 Subjective Versus Objective Measurement

The third aim was to determine if there is a discrepancy between traditional methods of activity questionnaires and objective methods of measuring near work, light exposure, and physical activity. The majority of studies evaluating near work and outdoor activity in children have been done through parent questionnaires, which are subject to poor recall, report, and parent biases. In addition, the wording of questionnaires has led to inconclusive results. For example, some studies have used education, intelligence,[74] and occupations requiring near work,[75,76] as surrogates for near work. Other studies have relied on diaries to quantify near work,[60] which was limited by subject compliance.

In this study, subjects completed a custom activity questionnaire, adapted from the Sydney Myopia Study,[49] with additional new items to address the increasing use of electronic products. The RangeLife device was used to obtain objective viewing data. Subjective diopter hours and objective diopter hours were calculated and compared. In addition, subjects wore an electronic device, the Actiwatch, to measure light intensity, physical activity, and sleep, and the objective data was compared with subjective survey responses.

The results of this study provide the first objective quantification of daily near work viewing distances for young adults. We predicted that not only would this demonstrate the feasibility of continuous, objective assessment of near and intermediate viewing distances using the RangeLife device, but would demonstrate that subjective measures of viewing distance do not reliably report actual viewing behaviors. These results support further use of the device to assess differences between groups of subjects who are emmetropic and myopic to begin to understand the influence of near work and viewing behavior in myopia.

Chapter 2

Continuous Objective Assessment of Near Work

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This chapter has been published as:

Williams R, Bakshi S, Ostrin EJ, Ostrin LA. Continuous Objective Assessment of Near Work. Sci Rep. 2019 May 6;9(1):6901

2.1 Introduction

Refractive development is regulated by a complex interaction between genetic, environmental, and behavioral factors.[20,21] Potential influences include time outdoors,[29,73,77] near work,[78,79] physical activity,[31,32] education,[80,81] nutrition,[82] and urbanization.[36] Several studies have reported an association between myopia and increased time studying and reading.[37,38,40,83] Rose, *et al.*, reported the highest odds ratio for myopia was for low time spent outdoors and a high time spent performing near work. However, results regarding the influence of near work have been conflicting, with some studies reporting no significant increased risk of myopia with increased near work.[30,84,85] Inconsistent results concerning the role of near work and myopia onset and progression are likely due to the variable and subjective nature by which near work has been assessed. Previous studies evaluating near work in children have traditionally been performed with parent questionnaires, which are subject to recall and parent biases.[51,52] In addition, surrogate measures are often used for near work. For example, some studies have used education, intelligence,[74] and occupation[75,76] as surrogates for near work.

Besides parent questionnaires, other studies have utilized diaries to quantify near work;[60] however, diaries are limited by subject compliance. Another technique previously utilized is the experience sampling method,[61-64] in which a pager was dispensed to subjects to send alerts throughout the day. Following each page, subjects were asked to complete as self-report about activities at the moment of the page. While this technique provided real-time sampling of activities and was shown to be capable of detecting the proportion of time spent doing near work, only discreet time points were sampled, typically 5-6 times throughout each day, and results depended on the response rate of the subject, averaging approximately 81%.[62]

"Diopter hours" is a metric used to quantify near work behaviors, and can be calculated from visual activity questionnaires. Diopter hours weights various near activities and viewing distances to determine a comprehensive value of near work exposure.[40,60] Diopter hours represents a weighted sum of the time spent in particular activities according to the accommodative demand required to perform the task. For example, hours spent reading at a near distance is given more weight than hours spent using a computer at an intermediate distance. However, this metric does not fully describe the complexity of viewing behaviors that may influence eye growth, such as the temporal properties of near viewing. Relevant viewing behaviors that might affect eye growth include the duration of near viewing sessions, intermittent breaks during near viewing, and absolute viewing distance.[41] Recent studies in children have shown that continuous reading and closer reading distances are associated with myopia.[83,86] Studies in animals have shown that experimental myopia is dependent on the temporal pattern of defocus or form deprivation, rather than the total duration of the myopiagenic stimulus.[43,45] For example, Napper, *et al*., showed that brief interruptions of form deprivation with normal vision significantly decreased the magnitude of myopia in chicks.[43] These findings suggest that reading breaks might be beneficial during prolonged near tasks. The development of a device that provides continuous, objective assessment of viewing distance offers the opportunity to ultimately assess such behaviors to understand their influence on myopia onset and progression in humans.

Wearable electronic monitoring devices are being more commonly utilized to objectively and precisely quantify environmental and behavior factors.[87] Several studies have utilized light, activity, and sleep monitors to begin to understand the influence of these behaviors in refractive development. Recent studies have provided objective evidence that light exposure is related to time of year,[66] and that myopic children tend to spend less time outdoors than emmetropic children.[73] Importantly, these studies revealed discrepancies between traditional subjective reports and objective data for both adults and children.[65,66]

One continuously measuring range finding device has been previously utilized to assess reading distance in adult high and low/non-myopes.[68] The authors used ultrasonic technology mounted on a headband to continuously measure and log viewing distance while subjects read a newspaper for 10 minutes. The results showed that the device was repeatable with high sensitivity, and that high myopes had a shorter working distance than low/non-myopes. Additionally, the authors found that the subject's self-reported reading distances varied greatly from objective measures. However, the device was not utilized in subjects' habitual environment and was limited to two 10 minute experimental periods in the lab.

The development and implementation of wearable devices for continuous measurement of working distance can be used in conjunction with previously validated light exposure and activity monitors to provide a more complete assessment of visual activity relevant to eye growth and myopia development. Here, we employed infrared time-of-flight technology to develop a spectacle frame mounted device, the RangeLife, for continuous measurement of working distance. Our goals were to calibrate and validate the RangeLife device according to known distances and subjects' activity logs, and to compare objective measures to traditional subjective visual activity questionnaires. Additional goals included assessing light exposure and activity levels during near viewing, and comparing near viewing behaviors in non-myopic and myopic young adults.

2.2 Methods

2.2.1 Instrumentation and Calibration.

All components for the RangeLife were acquired from Adafruit, USA. The RangeLife device consists of a time-of-flight distance sensor which uses a class 1 940 nm laser with nanosecond technology (VL53L0X). The time-of-flight principle is a method for measuring the distance between a sensor and an object, based on the time difference between the emission of a signal and its return to the sensor, after being reflected by an object, enabling accurate distance ranging regardless of the object's surface characteristics. The sensors were controlled by an Arduino microprocessor coupled to a real-time clock (DS3231 Precision RTC) and a micro secure digital (SD) card data logger (Feather M0 Adalogger). Technical specifications for the distance sensor can be found at https://www.adafruit.com/product/3317. Components were connected using the built-in Arduino Inter-Integrated Circuit (I2C) bus. Power was supplied by a rechargeable 2500 mAh lithium polymer battery to provide approximately 16 hours of continuous distance measurements. The sensor is 1 × 1 × 0.2 cm and attaches to the user's glasses, with a 1 m wire leading to the microprocessor which is housed with the RTC and battery in a plastic enclosure with a belt clip. The device was programmed to collect data continuously at 1 Hz and write onto files on the SD card. Open-source programming libraries for the sensor, clock, and data logger components were used to write running code for the device using the Arduino language. All code and schematics are available on request.

Four devices were constructed and used in this study. Each device was tested on one occasion by one observer for known distances from 0.05 to 2.0 m in 0.05 m intervals to assess stability of the measurements and generate a calibration function. For each device, the sensor was placed along a millimeter scale parallel to ground, and directed towards a wall. The device was set to begin recording at 1 Hz, and started at a position 0.05 m from the wall. Every 150 seconds, the device was moved away from the wall by 0.05 m. The recording continued until the device reached 2.0 m. The data were downloaded, and the distances measured by the device were plotted against actual distances from the millimeter scale. Data from all four devices were plotted and linear regression analysis was used to determine a calibration function.

Beam diameter refers to the width of the incident laser beam that bounces off of an object. The more narrow the beam diameter, the more precision the device will have to detect small objects in the line of sight. The device was directed towards a wall and projected onto a concentric millimeter scale. The beam diameter was determined for each of the four devices, for distances from 0.1 to 0.5 m in 0.1 m intervals. The observer viewed the beam through an infrared viewer to measure beam diameter at each distance. For 0.6 m and greater, the projected beam on the surface was too faint to detect with the infrared viewer; therefore, beam diameter was interpolated from 0.6 to 1 m. A linear regression was fit to the data, and the beam diameter was calculated in degrees.

2.2.2 Subject Testing

Subject testing was conducted with the four RangeLife devices described above. Healthy adult subjects ages 22–41 (n = 23) participated in this study. The study was approved by the Committee for Protection of Human Subjects at the University of Houston and was in accordance with the tenets of the Declaration of Helsinki. Subjects provided informed consent after learning the details of the study. All subjects had best corrected visual acuity of 20/20 or better and no ocular disease.

Subjects answered a custom activity questionnaire, the University of Houston Near work, Environment, Activity, and Refraction (UH NEAR) survey (see Appendix 1), adapted from previously published visual activity surveys.[49] Refractive status (myopic or non-myopic) was determined by self-report from the questionnaire using an indirect method technique, which has been shown to have reasonable sensitivity and specificity for determining whether a subject is myopic.[88] Additionally, subjects were drawn from the student and staff population of the University of Houston College of Optometry and were confident in reporting their refractive status. Previously utilized visual activity questionnaires do not take into account the abundant use of hand held devices, such as smartphones and tablets, that has become more prevalent in the past decade. Therefore, we created the UH NEAR survey, adapted not only from near activity questionnaires, such as the Sydney Myopia Study,[49] but also from public health and psychology questionnaires. Items were created to account for electronic and printed viewing tasks separately, and reduce redundancy and uncertainty between items. For example, video games, an item commonly included in published questionnaires, creates ambiguous results because subjects engage in video games at near (hand held devices), intermediate (computer) and far (television) distances. We attempted to clarify these factors through the UH NEAR survey.

RangeLife devices were fully charged prior to wear, then mounted on the right temple of a spectacle frame directed approximately 4° nasally, so that the beam was aligned at midline at 0.40 m. Devices were mounted to subjects' habitual spectacle frame, or, if the subject did not wear spectacles, on a provided frame with plano lenses. The wire ran along the right temple, behind the ear, and to an enclosure, measuring 9 × 6 × 4 cm, that held all of the components. The enclosure was attached via a belt clip or placed in the subject's pocket.

Subjects were asked to wear the device from the time they woke up until going to bed, except for showering or swimming. Because the device was affixed to the temple of the spectacle frame, subjects were encouraged to turn their head rather than rotating their eyes to ensure the device was measuring along the line of sight. Subjects kept a detailed log of activities while the device was worn to compare objectively measured distances to corresponding activities. Additionally, subjects wore an actigraph and light sensor device (Actiwatch Spectrum, Respironics, Phillips, OR, USA) while wearing the RangeLife so that patterns of light exposure and activity could be correlated to viewing distance. Light exposure (lux) and physical activity (counts per minute) were averaged over one minute epochs, as previously described.[66] Time outdoors was defined as minutes per day exposed to greater than 1000 lux.[73] Following each full day of wear, RangeLife data were downloaded and binned into 0.10 m intervals to calculate the number of minutes per day spent viewing distances from 0.10 to 1.0 m. Distances were categorized from very near viewing (0.1 cm) to "far" viewing (>1.0 m, Table 1).

Table 2.1: Viewing distance classifications from 0.1 to >1.0 m with example activities for each category.

Range	Viewing Distance	Classification	Example Activities
Near	0.1 to <0.2 m	Extremely near	Hand held devices
	0.2 to <0.3 m	Very near	Hand held devices, printed material
	0.3 to <0.4 m	Fairly near	Printed material
	0.4 to < 0.5 m	Near	Printed material, computer monitor
	0.5 to < 0.6 m	Moderately near	Computer monitor
Intermediate	0.6 to < 0.7 m	Near intermediate	Computer monitor
	0.7 to <0.8 m	Intermediate	Conversing with others
	0.8 to <0.9 m	Moderately intermediate	Conversing with others
	0.9 to <1.0 m	Far intermediate	Conversing with others, cooking
Far	≥1.0 m	Far	Television viewing, driving, outdoor activity

2.2.3 Data Analysis

Data are presented as mean ± standard error unless otherwise noted. Calibration and beam diameter data were fit with linear regressions. Subjective diopter hours (dh) were calculated from the questionnaire using Eq. 1, and objective diopter hours were calculated from RangeLife data using Eq. 2. Both subjective and objective diopter hours were calculated separately for weekdays and for weekends, then mean daily diopter hours were calculated using Eq. 3. Weekday versus weekend data, and subjective versus objective data for each subject were compared using paired two-tailed t-tests. Data for refractive error groups were compared using unpaired two-tailed t-tests with equal variance. Alpha level <0.05 was considered significant.

$$\begin{aligned}\text{Subjective Diopter Hours} = {} & [3 \times (\text{hours reading print} \\ & + \text{hours drawing, painting writing} \\ & + \text{hours using hand-held devices})] \\ & + [2 \times (\text{hours using computers} \\ & + \text{playing board games or cards})] \\ & +[1 \times (\text{hours watching tv})] \qquad (1)\end{aligned}$$

$$\begin{aligned}\text{Objective Diopter Hours} = {} & (3 \times \text{hours viewing } 0.1 \text{ m to } < 0.5 \text{ m}) \\ & + (2 \times \text{hours viewing } 0.5 \text{ m to } < 0.8 \text{ m}) \\ & + (1 \times \text{hours viewing } 0.8 \text{ m to } < 100 \text{ m}) \qquad (2)\end{aligned}$$

$$\text{Daily diopter hours} = [(\text{weekday diopter hours} \times 5) + (\text{weekend diopter hours} \times 2)]/7 \qquad (3)$$

2.3 Results

2.3.1 Instrumentation

During calibration testing, each of the four devices showed high stability with no noise in the recording. Raw data from one representative device are shown in Fig. 1A. The devices demonstrated a linear relationship with measured distances from 0.10 to 1.2 m. For the mean of all four devices, the regression equation was $y = 0.9446x + 0.422$ (Fig. 1B). Beyond 1.2 m, distances were registered by the devices as "out of range". For all remaining analyses, distances from 0.1 to <0.6 m were considered "near", from 0.6 to <1.0 m were considered to "intermediate", and ≥1.0 m were considered "far." The standard deviation of the measurement at 0.10 m was ±0.002 m, at 0.40 m was ±0.003 m, and at 1.0 m was ±0.012 m. The infrared beam diameter ranged from 0.05 m (at 0.1 m distance) to 0.47 m (at 1.0 m distance). The beam diameter increased linearly with distance ($y = 0.4675x + 0.0048$, Fig. 1C), which represents an extrapolated beam width of 27°.

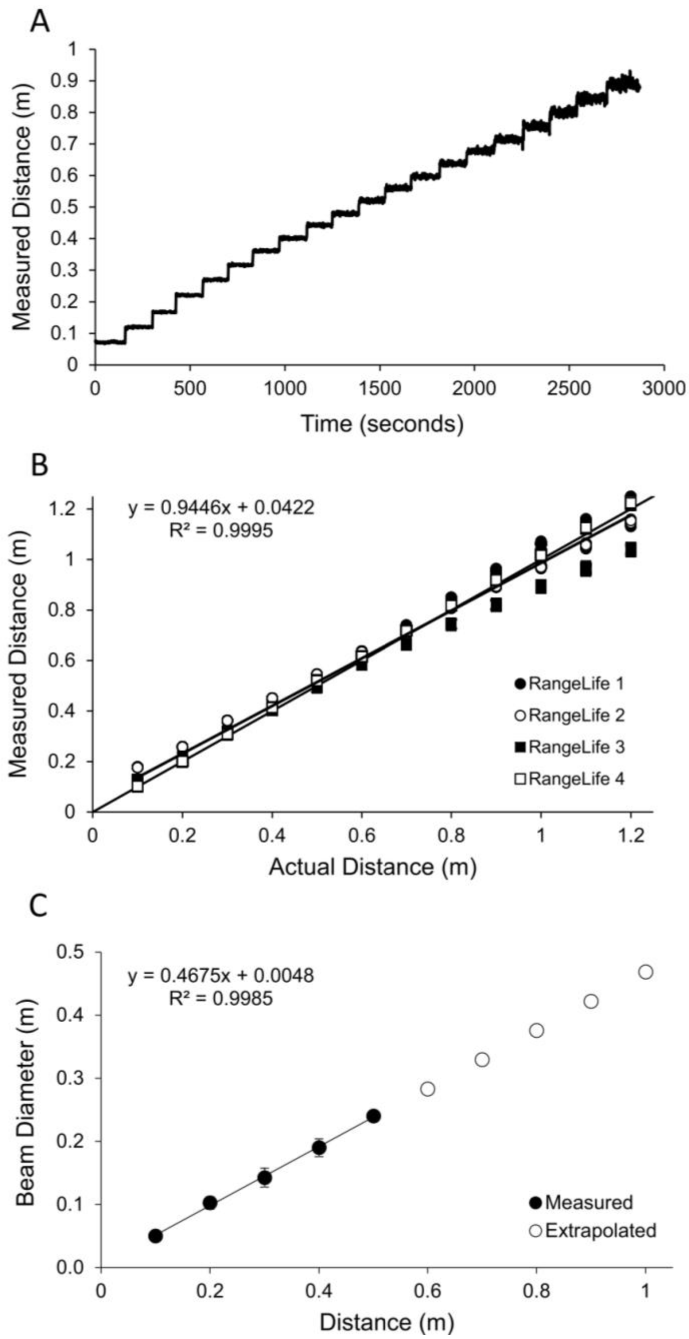


Figure 2.1: (A) Representative example of raw data from one RangeLife device as it is moved away from a wall from 0.05 to 1.0 m in 0.05 m steps approximately every 150 seconds. **(B)** Linear regression (solid line) showing the relationship between actual distances versus device-measured distances for each of the four devices. Dashed line represents the 1:1 line. **(C)** Infrared beam diameter with distance from a surface. Solid symbols are measured values and open symbols are extrapolated from the linear regression (solid line). Error bars represent standard deviation for the four devices.

2.3.2 Subjects

Mean subject age was 27.7 ± 5.6 years, with a range of 22–41 (10 female, 13 male). Thirteen subjects were myopic and 10 subjects were non-myopic, with no significant difference in age between refractive error groups ($p = 0.17$).

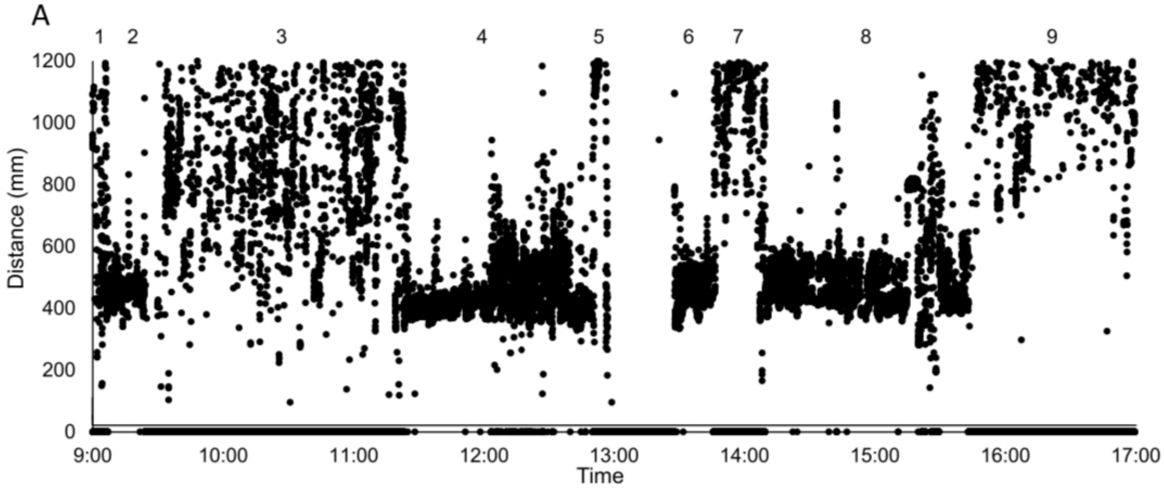
2.3.3 Subjective Data

One subject with mean daily diopter hours of 63.57 dh was identified as an outlier (Tukey outlier test) and not included in data analysis. Subjective diopter hours for all other subjects was greater for weekdays (26.64 ± 9.16 dh) than for weekends (23.25 ± 10.75 dh, $p = 0.02$). Subjective daily diopter hours were not significantly different between refractive error groups for weekdays ($p = 0.27$) or weekends ($p = 0.93$).

2.3.4. Objective Data

For objective measures from the RangeLife device, 19 subjects wore the device for two days each, one weekday and one weekend day. Three subjects wore the device for one weekday only, and one subject wore the device for one weekend day only. On average, subjects wore the device for 12.7 ± 2.2 hours on the weekday and 12.4 ± 1.7 hours on the weekend day ($p = 0.61$). Based on all subjects' activity logs and objectively measured distance data, activities were correlated to measured distances at corresponding times. Example activities for each distance are provided in Table 1. Raw data from the RangeLife for one subject for a weekday, 9:00 am to 5:00 pm, are shown in Fig. 2A, and correlating activities from the subject's activity log are provided in Fig. 2B.

A



B

	Time	Activity
1	9:00 am - 9:12 am	Walking indoors
2	9:12 am - 9:24 am	Sitting at desk viewing computer
3	9:24 am - 11:23 am	Walking indoors
4	11:23 am - 12:50 pm	Sitting at desk viewing computer
5	12:50 pm - 1:28 pm	In a meeting
6	1:28 pm - 1:44 pm	Sitting at desk viewing computer
7	1:44 pm - 2:12 pm	Speaking to colleague
8	2:12 pm - 3:21 pm	Sitting at desk viewing computer
9	3:21 pm - 5:00 pm	In a meeting

Figure 2.2: (A) Raw distance data collected at 1 Hz from the RangeLife for one representative subject on a weekday, 9:00 am to 5:00 pm. Gaps in the data represent "out-of-range" viewing, >1200 mm. Numbers 1–9 represent activities from the subject's activity log, and are listed in panel **(B)**.

Comparisons between objectively measured weekday versus weekend hours were calculated for the 19 subjects who wore the device on both days. Objective diopter hours was greater for weekdays (14.73 ± 4.67 dh) than for weekends (11.91 ± 4.82 dh, $p = 0.05$). When analyzed by refractive status, objective weekday diopter hours for non-myopic subjects was 12.73 ± 4.99 dh, which was not significantly different than weekend diopter hours, 11.81 ± 3.7 dh ($p = 0.34$). For myopic subjects, objective weekday diopter hours was 16.4 ± 3.52 dh, which was also not significantly different than weekend diopter hours, 11.97 ± 5.53 ($p = 0.10$). While myopic subjects tended to have greater diopter hours during the week than non-myopic subjects (16.4 vs 11.97 dh, respectively), the differences did not reach statistical significance ($p = 0.06$). When weekday and weekend objective diopter hours were weighted for the week (Eq. 3), the mean daily objective diopters for non-myopes was 12.66 ± 5.15 dh, and for myopes was 14.98 ± 2.86 dh ($p = 0.22$).

Because there were no significant differences between refractive error groups, the remaining analyses were performed for non-myopic and myopic subjects together. Time spent viewing in each near to intermediate 0.1 m bin, as well as far viewing, for weekdays and weekends, is shown in Fig. 3. While there was a tendency for subjects to spend more time viewing near to intermediate distances and less time viewing distance on weekdays, the only 0.1 m interval in which the time was significantly different between days was for the 0.5–0.6 m range ($p = 0.04$).

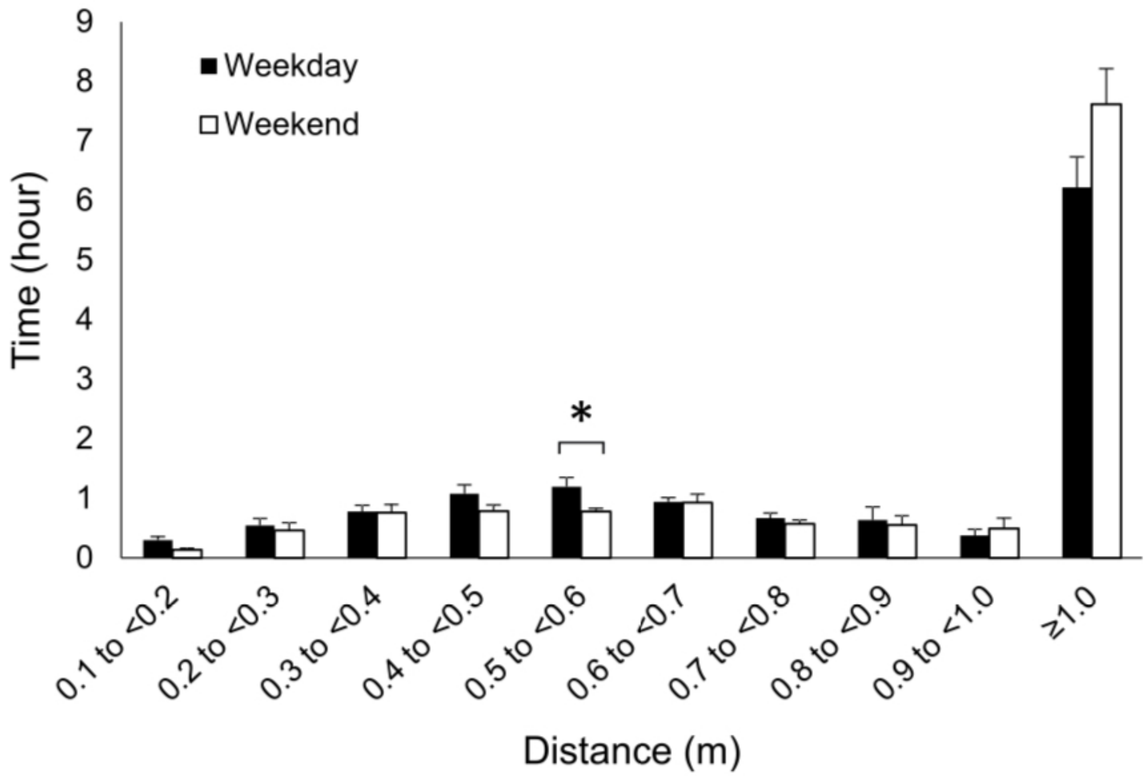


Figure 2.3: Objectively measured mean daily time (mean hours ± standard error) viewing distances from 0.1 to greater than 1.0 m for weekdays (solid bars) and weekends (open bars). Time spent viewing distances from 0.5 to <0.6 m was significantly greater on weekdays at $p < 0.05$, while differences in other binned distances did not reach statistical significance *$p < 0.05$.

Near to intermediate working distances (0.1 to <1.0 m) were compared to objective measurements of light exposure and activity, as measured with the Actiwatch. Data for a representative subject are shown in Fig. 4A,B, and data for all subjects are shown in Fig. 4C,D. Subjects primarily engaged in near to intermediate working distances when they were exposed to indoor photopic luminance levels from 10 to 1000 lux, with a mean of 59.10 ± 4.78% of near to intermediate working distances detected in this light level range. Near to intermediate working distances were also detected when the subjects were exposed to mesopic luminance levels less than 10 lux, with a mean of 35.01 ± 4.94% of near to intermediate working distances detected in this light level range. There were minimal near to intermediate working distances measured when the subjects were exposed to outdoor illumination greater than 1000 lux (4.34 ± 1.27%). For physical activity, 80.03 ± 2.11% of near to intermediate working distances were measured while subjects demonstrated sedentary physical activity levels (<320 counts per minute)[89], with 19.09 ± 1.95% of near to intermediate working distances measured while the subjects demonstrated light physical activity (320 to 1048 counts per minute). 0.88 ± 0.28% of near to intermediate working distances were detected when the subject was engaged in moderate or vigorous activity (>1048 counts per minute).

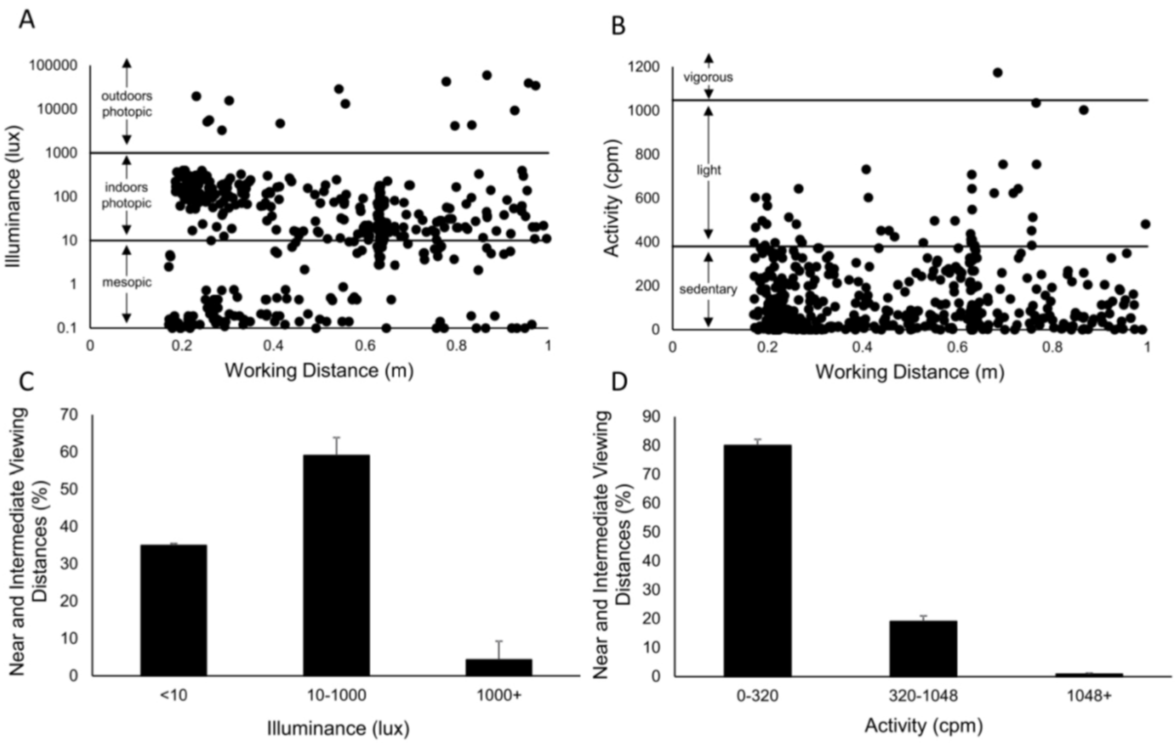


Figure 2.4: Objectively measured working distance (RangeLife) plotted with illuminance (lux) and activity counts per minute (cpm) as measured with the Actiwatch for a representative subject (**A,B**) and all subjects (**C,D**, mean ± standard error).

2.3.5. Subjective Versus Objective Data

From the questionnaire, time spent in near and intermediate work was determined by asking subjects to estimate the amount of hours spent viewing a computer, viewing a hand- held device, reading printed material, drawing, painting or writing, and playing cards or board games. Subjects reported a mean daily average of 10.34 ± 0.85 hours engaged in near and intermediate work. From the RangeLife device, time spent in near and intermediate viewing was determined by summing the amount of time spent viewing distances from 0.1 to <1.0 m. Objectively measured mean daily time viewing near and intermediate distances was 6.25 ± 0.39 hours. Objective measures were significantly less than subjective reports ($p = 0.002$), and there were no correlations between subjective reports and objective measures for either weekdays ($p = 0.78$) or weekends ($p = 0.76$, Fig. 5).

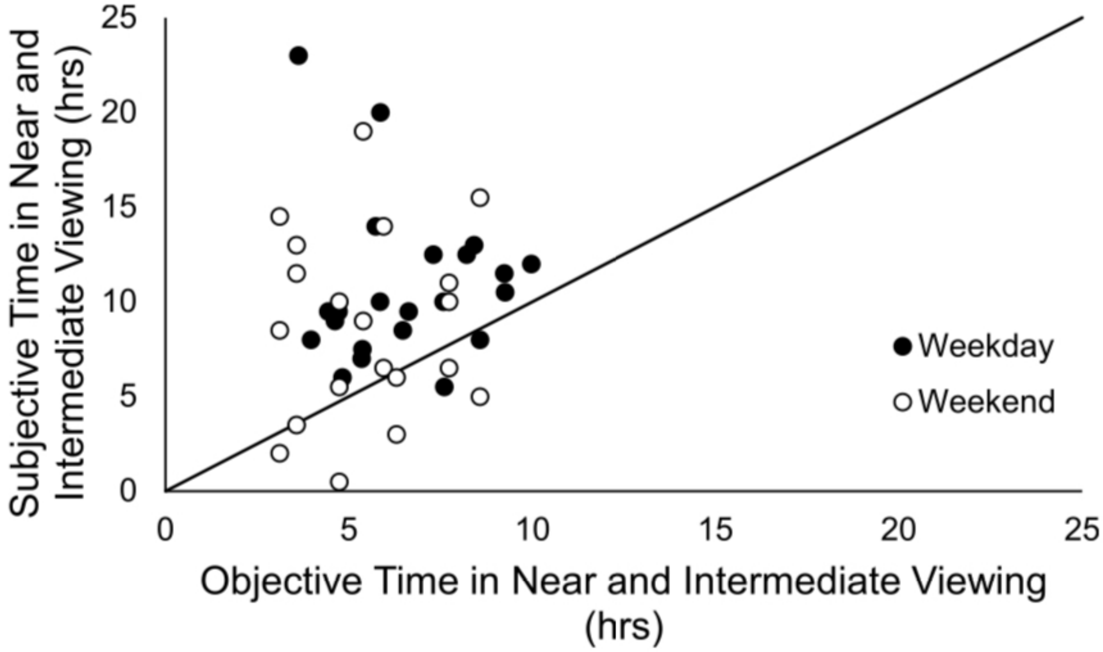


Figure 2.5: Objectively measured time spent viewing near to intermediate distances versus subjectively reported time for weekdays (solid symbols) and weekends (open symbols). Line represents 1:1 relationship.

Time spent outdoors was determined subjectively by asking the subjects to estimate the amount of time spent outdoors in physical activity, leisure activity, and driving or riding in a car. Subjective reports of time spent outdoors was 2.75 ± 0.30 hours per day. Objective measurement of time outdoors was determined from the Actiwatch by summing the number of minutes per day the subject was exposed to greater than 1000 lux, which was 1.44 ± 0.46 hours per day, and significantly less than subjectively reported time outdoors ($p = 0.002$).

2.4 Discussion

The results of this study demonstrate the validity and feasibility of continuous, objective assessment of near and intermediate viewing distances using the RangeLife device. We have presented the first objective quantification of viewing distances throughout a day for young adults. We developed a classification scheme for categorizing near to intermediate distances in 0.1 m bins, and established a method for calculating objective diopter hours. These results support further use of the device to assess differences between larger groups of subjects of various ages and refractive status to understand the influence of near work and viewing behavior in myopia. In particular, the device can be used in future studies to assess not only working distance, but also temporal properties of viewing behaviors. Here, near and intermediate viewing was assessed during weekdays and weekends to begin to understand how behaviors might vary based on school/work days versus leisure days. In young adult subjects, we found that objective diopter hours were greater for weekdays (14.73 dh) versus weekends (11.91 dh). While there was a trend for myopic subjects to spend more time engaged in near and intermediate viewing than non-myopic subjects, the difference did not reach statistical significance. We speculate that a larger sample size might clarify whether differences in viewing behaviors exists between refractive error groups in young adults. However, it is not unexpected that adult subjects with fairly homogenous occupations (i.e. students and staff at a university) would demonstrate similar behaviors. Saw, *et al.*, reported that age of onset of myopia was related to close up work activity in early childhood, but not close up work as a young adult; subjects were all military conscripts.[81] Future studies aimed at assessing objectively measured near viewing patterns in younger subjects are imperative in determining the role of near viewing behaviors in refractive development.

By analyzing multiple objective measures of behavior, including working distance using the RangeLife and light exposure and physical activity using an Actiwatch, we can begin to tease apart specific behaviors that may influence eye growth. We found that the majority of near and intermediate work was carried out while the subjects were exposed to mesopic (<10 lux) and indoor photopic (<1000 lux) illuminance. Additionally, subjects were primarily engaged in a sedentary level of physical activity during near and intermediate viewing. Several studies have suggested that bright outdoor light exposure is protective for myopia development;[77,90] however, it remains unclear if viewing behaviors during bright light exposure, such as engaging in near work while outdoors, might contribute to myopia development. Future studies making use of objective measures for these multifactorial components will help to elucidate contributing behaviors to myopia, and may allow researchers and clinicians to suggest modifiable behaviors that will reduce the onset and progression of myopia.

In this study, subjective and objective diopter hours were calculated to determine a near work index using each method. Diopter hours weights various near activities and viewing distances to determine a comprehensive value of near work exposure. The diopter hours metric was introduced by Zadnik, *et al.*,[22] in 1994 as part of the ORINDA study, and has been utilized in several studies, albeit using different calculations.[40,60] For example, Zadnik, *et al.*, determined diopter hours by adding together "three times the number of hours spent reading (for pleasure or studying), two times the number of hours spent playing video-type games, and the number of hours spent watching television," and reported mean 53.8 ± 26.8 dh in eighth grade children.[40] Saw, *et al.*, calculated diopter hours by multiplying various near work activities by the reciprocal of the distance for each activity, and reported ranges from 0.008 to 0.21.[60] Here, subjective diopter hours from the questionnaire averaged 25.67 ± 9.2 dh and objective hours from the RangeLife averaged 14.0 ± 4.0 dh. It is not unexpected that there would be discrepancies between subjective and objective diopter hours because of the variability in subjective data, and the differences in how subjective and objective diopter hours were calculated here. Therefore, the metric is best used as a relative measure to compare refractive error groups or across time periods when using a similar methodology.

Studies employing objective wearable sensors to assess reading distance[68] and time outdoors[65,66] have reported discrepancies between subjective reports and objective measures. We used the newly developed UH NEAR survey for subjective reports of visual activity. However, we still found variability between subjective and objective quantification of viewing distances, with most subjects overestimating time spent in near work as compared to objective measures derived from the RangeLife. These findings further justify implementation of objective measures to quantify environmental and behavioral factors. While objective measures are ideal for precisely quantifying visual activity, questionnaires will still be a beneficial supplement to objective measures to fully characterize behaviors.

We found that the RangeLife device was capable of logging continuous measures of viewing distance with high sample rate (1 Hz) and no noise in the data. Continuous measurements with a high sample rate will allow for a more precise quantification of viewing distance, which, in future studies, can be analyzed in terms of the duration of continued near work with quantification of near viewing breaks that may be interspersed within the near work task. The absence of noise in the data eliminates the need for filtering and potential loss of data. Another important feature of range sensing devices is that they have a narrow beam diameter and can detect when the line of sight is directed at small targets, such as hand-held electronic devices. The beam diameter of the RangeLife is narrow enough such that it was able to detect hand held devices, books, and computer monitors. These characteristics are ideal for assessing near viewing behaviors that have been linked to refractive error, including the duration and frequency of near work,[39,83] distance of reading material,[68] and other reading habits.[91]

The RangeLife device presented some limitations in measuring viewing distance. The reliable measurable range was limited to 0.1 to 1.0 m, and therefore, distances greater than 1.0 m could not be quantified and were classified as "far" for the purpose of this study. Another limitation was that the device was mounted to a spectacle frame and therefore not necessarily aligned with the line of sight, which may have resulted in some inaccuracies as subjects rotated their eyes. We attempted to minimize this confounding factor by encouraging subjects to turn their head towards targets rather than rotating their eyes. A previous study using a similar device tested the directional sensitivity and found that the device retained its sensitivity even when the target was at a substantial angle from the measuring beam.[68] Additionally, the authors found that the region of maximal sensitivity was about 30° for working distances of 40 to 100 cm. Therefore, small rotations from the line of sight are not expected to have a large impact on the measured viewing distance; however, future studies are aimed at quantifying the directional sensitivity for the RangeLife. Another limitation was that the device transmits data via a cord leading to an enclosure with a belt clip, which might present some difficulty with subjects who are involved in sports or other vigorous physical activity. Our adult subjects did not report problems in the current study, even during exercise. However, future instrument optimization is aimed at designing the components such that data can be stored within the sensor, eliminating the need for a wired enclosure.

In conclusion, the RangeLife was shown to provide continuous, objective, and reliable measures of near and intermediate viewing distances. Additionally, significant differences were demonstrated between RangeLife measures and traditional questionnaire data. The RangeLife device can be further implemented to assess viewing behaviors that may influence refractive error development in children and young adults.

2.5 Acknowledgments

Supported in part by NIH NEI P30 EY007551 and T35 EY007088.

Chapter 3

Conclusions

3.1 Summary of Results

The first aim of this study was to develop a device for continuous objective measurement of working distance. The RangeLife devices were validated and calibrated, and demonstrated the feasibility of continuous, objective assessment of near and intermediate viewing distances. The use of these novel devices is the first objective quantification of viewing distances throughout an entire day in young adults. The study established a classification scheme for categorizing near to intermediate distances. The study also established a method for calculating objective diopter hours. The results demonstrated that objective diopter hours were greater for weekdays versus weekends in our subjects.

The second aim was to compare objective working distance data with objective data of light exposure, physical activity, and sleep. The RangeLife and Actiwatch devices were utilized to achieve this aim. The results found that near and intermediate work were associated with low illuminance and a sedentary state.

The third aim was to determine if there is a discrepancy between traditional methods of activity questionnaires and objective methods of measuring near work, light exposure, and physical activity. Using the UH NEAR Survey for subjective reports and the RangeLife and Actiwatch for objective measures, the results demonstrated variability between subjective and objective quantification of viewing distance. Interestingly, the young adult subjects mostly overestimated the time they spent performing near work compared to objective data.

3.2 Significance

This research has a high potential for a positive impact in the clinically relevant area of myopia. The ultimate goal of this work was to provide the scientific basis for effective environmental and behavioral modifications to slow myopia progression. Myopia is an epidemic, with a growing prevalence in Eastern Asian countries,[92-95] as well as in the United States,[96,97] and other non-Asian countries.[98] With increases in myopia, the prevalence of high myopia is also increasing, reported to have increased 8 fold from the 1970s to the 2000s.[2] Efforts have increased to understand the regulatory mechanisms underlying eye growth due to the potentially blinding complications and socioeconomic health problems associated with myopia, which is a leading cause of treatable blindness.[99] Myopia is associated with retinal detachment,[100,101] macular degeneration, cataract,[8,96] and glaucoma.[102,103] Retinal complications in myopia reflect the retinal stretching[11] and thinning[12] that accompany excessive axial elongation. In high myopes, reports show that visual acuity,[14] contrast sensitivity,[15] and visual field sensitivity[16] are decreased. By reducing the prevalence and progression of myopia, significant reductions in the socio-economic burden and improvements in quality of life can be achieved.

At birth, humans, as well as many other species, are generally hyperopic,[17,104] and undergo emmetropization using visual cues to modulate eye growth, reduce refractive error, and bring the focal plane to the retina.[18,19] Evidence suggests that refractive development is regulated by a complex interaction between genetic and environmental factors.[20,21] Studies in animal models provide evidence of active emmetropization regulated by visual feedback.[1] In humans, outdoor time has been shown to be protective against myopia onset.[29,73,77,78] Other potential environmental and behavioral influences include near work, physical activity,[31,32] nutrition,[82] and urbanization.[36] Previous studies have found an association between myopia and increased time studying and reading.[40] Rose, et al., reported the highest odds ratio for myopia was for a low amount of time spent outdoors and a high amount of time spent performing near work. Mechanisms behind these relationships remain elusive. Findings from this study can ultimately lead to recommendations for modifications with respect to near work behaviors or time outdoors to prevent myopia onset and slow progression in children.

We developed a novel instrument that continuously measures working distance. Through the development and implementation of the RangeLife device for continuous, objective measurement of working distance, we were able to quantify near work behaviors believed to contribute to myopia that have only been subjectively estimated to date.

Additionally, we developed an updated visual activity questionnaire, the UH NEAR Survey, for adults and children. By taking into account new technologies and lifestyle changes that have come about since previous visual activity questionnaires were designed, we can more accurately describe near activities that children and adults regularly engage in, including the use of hand held devices, video games and computers.

We combined subjective and objective measures to get a more complete description of all environmental and behavioral factors simultaneously. Previous studies have assessed objective measures of light exposure, activity, and time outdoors. We combined these measures along with near work measurements, using novel objective and subjective methods, to provide a complete description of visual activity.

3.3 Future Research Directions

The UH NEAR Survey was developed as a near work and activity questionnaire, adapted from the Sydney Myopia Study.[49] For use in future studies using children as subjects, the questionnaire should be adapted further in order to properly account for time spent at near during school hours. To achieve this, private and public teachers and administrators can be consulted to understand near work, electronic device use, and time spent outdoors while children are at school.

Using the UH NEAR Survey to compare subjective responses with objective data, discrepancies were observed between subjective and objective diopter hours. Therefore, in future studies, researchers should aim to use objective methods of measurement for data collection, with subjective methods used primarily as supplementation.

The results of this study demonstrate the validity and feasibility of continuous, objective assessment of near and intermediate viewing distances using the RangeLife device. In addition, the device can be used in future studies to assess not only working distance, but also temporal properties of viewing behaviors. The RangeLife device is not without its limitations. Future instrument optimization is aimed at designing the components to be wireless and waterproof. With further testing and implementation of these devices in populations of all ages, from elementary school through adults, and along with previously validated objective devices to measure light exposure, a complete representation of the environmental and behavioral influences on eye growth can be assessed. Previous research has shown that age of onset of myopia is related to close up work activity in early childhood. For this reason, it is imperative that future studies assess near viewing patterns in younger subjects in order to determine if near viewing behaviors play a role in refractive development. Studies such as these may ultimately help develop recommendations for behaviors to prevent or slow the progression of myopia.

In this study, multiple objective measures of behavior were analyzed using the RangeLife and Actiwatch. With further use of these devices together, we can begin to understand the relationship between specific behaviors that may influence eye growth. For example, future studies may consider assessing viewing behaviors during bright light exposure, such as engaging in near work while outdoors. Conclusions based on multifactorial components may allow researchers and clinicians to suggest modifiable behaviors to reduce onset and progression of myopia.

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Appendix

A. Adult Visual Activity Questionnaire

Date of birth: ________________________________

Are you Hispanic or Latino? _____yes ______no

Race (circle): white black/African American

Native American Asian Other: ___________________

Do you wear glasses or contact lenses? _____yes ______no

If yes, is the correction for seeing: _____ distance ___ __near ___ __both

Are your glasses bifocals? _____yes ______no ______unsure

If known, please provide your prescription: Right eye: ____________________________

Left eye: _____________________________

Age when started wearing: _______ years old

What is your occupation? ____

Please mark the number of hours per day you spend involved in these activities:

	Weekday						Weekend Day (hours)					
	Not at all	Less than 1 hour	1-2 hours	3-4 hours	5-6 hours	7+ hours	Not at all	Less than 1	1-2	3-4	5-6	7+
1. Outdoor physical activities (sports, hiking, walking, biking, running)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2. Outdoor leisure activities (eating, sitting or resting, outdoors)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3. Driving or riding in a vehicle (car, bus or train)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4. Indoor physical activities (exercise, sports, martial arts)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6. Viewing a TV screen (movies, video games)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7. Viewing a computer screen (work, browsing, computer games)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8. Viewing a handheld electronic device (smart phone, tablet, handheld video games)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

9. Reading printed material (newpaper, magazines, books, work)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
11. Drawing, painting, or writing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
14. Playing card or board games (not electronic)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

15. How many hours of sleep to you get on a week night? ____ weekend night? ____