tvst

Pediatric Ophthalmology & Strabismus

Objective Quantification and Topographic Dioptric Demand of Near-Work

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Received: September 22, 2022
Accepted: January 6, 2023
Published: February 17, 2023

Keywords: dioptric demand; topographical dioptric demand; objective quantification of near-work; spatiotemporal point of regard

Citation: Wagner P, Ho A, Kim J. Objective quantification and topographic dioptric demand of near-work. Transl Vis Sci Technol. 2023;12(2):28, https://doi.org/10.1167/tvst.12.2.28

Purpose: The assessment of myopigenic environmental risk factors such as near-work relies on subjective data. Although diaries and questionnaires on near-work show correlation to some degree, it remains unknown how they may correspond to ground truth. This is an important consideration because valid estimates of near-work have great utility for understanding the mechanisms by which dioptric demand drives excessive eye-growth, which is not yet entirely understood. To this end, we assessed a novel eye-tracking system to quantify near-work.

Method: We compared subjective entries from diaries to objective data on accommodative demand acquired with a three-dimensional eye-tracker in 20 participants. Each test involved approximately one-hour exposure to ecological near-work environments. Furthermore, topographical dioptric demand maps were computed in retinal coordinates.

Results: Our study suggests a frequent mismatch between objectively and subjectively labeled data of near-work tasks (concordance 74.6%). Objective and subjective estimates of dioptric demand showed a moderate correlation and were not significantly different ($R^2 = 0.59$, $P = .35$). Instead, accommodative demand with an agreement between objective and subjective near-work labels showed a high correlation and were significantly different ($R^2 = 0.79$, $P = .016$). The accumulated topographical dioptric demand of ecological near-work environments did not present myopigenic defocus stimuli to the retina periphery. Thus extreme close-up near-work presented peripheral defocus stimuli that have been proposed to curb excessive eye growth.

Conclusions: The proposed objective measurement method may provide improvements over subjective methods for estimating near-work parameters.

Translational Relevance: The topographic dioptric demand maps highlight a possible conflict of causal mechanisms of the two myopia models: "excessive near-work" and "peripheral optical defocus."

Introduction

Retrospective and longitudinal studies indicate that excessive near-work might lead to excessive eye elongation (myopia).[1–3] Optical interventions such as spectacles, contact lenses, or refractive surgery successfully correct myopia (that is, only providing clear vision without intentionally influencing progression). However, they are also associated with a high economic and social burden.[4] There is also an increasing risk of sight-threatening complications with increasing age and degree of myopia.[5] Current and future generations will also likely experience an increase in visual near-work behaviors because of the increased use of digital devices, prompting the need to better understand the myopigenic risk factors of near-work.[6]

The underlying visual mechanisms of near-work that drive myopia are not fully understood. Some studies proposed that excessive accommodation during near-work (the eye's capability to focus images of near objects sharply onto the retina) might contribute to myopia.[7,8] Other researchers proposed that myopia is optically guided.[9,10] Studies have shown that a posterior layer (i.e., the choroid) of the eye experiences a growth stimulus that moves the retina toward the eye's imaging plane.[11,12] Thereby, while the eye is constantly accommodating to focus images sharply at the region of highest visual acuity (i.e., the fovea), peripheral images from the scene might be presented in front or behind the retina because of the topographic variations of ecological environments.[10]

One of the major challenges to overcome in long-term behavioral studies is the lack of objective measurement tools that can estimate the parameters of complex ecological environments. Although questionnaires can indicate valuable information about behavioral risk factors, there is a risk of bias and subjectivity influencing the validity of data.[13] Current wearable devices estimating near-work in real-life settings using single time-of-flight sensors have found a mismatch between objective and subjective reports on near-work.[14,15] However, single time-of-flight sensors only measure object distances at a limited range and within a narrow field angle (much smaller than the field of fixations). These time-of-flight sensors also introduce inaccuracy at best and systematic biases at worst because they do not take into account the direction of gaze.[16]

To overcome these limitations, we recently developed a three-dimensional (3D) eye-tracker (3D-Eye-Tracker) capable of recording spatiotemporal scene information with associated gaze estimates in real-world scenarios.[17] The distances to objects that a participant is gazing at (i.e., the foveal dioptric demand) can be estimated continuously. Thus the foveal dioptric demand represents the accommodative stimulus for the eye. Whereas accommodating at near objects requires effort from the human eye, dis-accommodating to farther objects is associated with reduced effort. Hence, the foveal dioptric demand can serve as a surrogate for near-work as it quantifies the dioptric demand the eye is exposed to. Furthermore, the depth information surrounding the participant's gaze can be mapped (dioptric maps in eye coordinate space) to indicate the spatial diversity of the scene as it would be presented to the eye. Current literature has estimated dioptric maps over brief periods of time.[18,19] Still, temporal accumulative estimates of dioptric demand from dynamic real-world scenarios have not been available because of limited technical solutions.

To address the outlined shortcomings, this study compared objective and subjective data obtained during unsupervised viewing in habitual near-work environments. A secondary aim of the study is to quantify and characterize the ecological dioptric maps of real-world scenarios to which the eyes are exposed.

Method

Participants

We recruited 20 participants from the general public, including author P.W. The study was approved by the Human Research Ethics Committee of the University of New South Wales Sydney (HC190522) in accordance with the Declaration of Helsinki and the National Statement on Ethical Conduct in Humans (2007, updated 2018). All participants provided written informed consent before commencement of the study. A vision screening was performed to establish eligibility with respect to the inclusion/exclusion criteria. Adults with good general eye health were included in the study. Exclusion criteria were any monocular habitual visual acuity (uncorrected or corrected with spherical contact lenses) below 6/7.5 (80%) (i.e., spectacles used as a corrective device were excluded) presbyopia, binocular vision abnormalities, and unusual pupil findings, including drug use affecting pupil size or shape. Data from two participants were excluded because of incompleteness (missing point-cloud) and frequent occlusion of the time-of-flight camera with facial hair that led to interference of measurements.

Objective Dioptric Demand Measurement of Habitual Behaviors

In a previous work we evaluated the gaze mapping accuracy within 3D scene environments using a novel 3D-Eye-Tracker.[17] For this study, we used this 3D-Eye-Tracker to acquire participants' dioptric demand in spatiotemporally diverse ecological environments. The 3D-Eye-Tracker combines head-mounted eye-tracking (Core–binocular; Pupil Labs GmbH, Berlin, Germany)[20,21] and time-of-flight camera technology (Pico Flexx; PMD Technologies AG, Siegen, Germany)[22] to map gaze estimates onto 3D point clouds taken from the participant's vantage point. To record eye-tracking data, Pupil Labs' open-source software package "Pupil" was used (PLPupil, version 1.21-5). A custom software plugin was developed to temporally align the 3D point cloud with PLPupil's eye-tracking data (Pico Flexx Depth Plugin–Backend version: f24533a, Plugin version: 0fd0b3f).[23] Mapped gaze estimates were determined from high-speed eye cameras (120Hz binocular) within a 0.11 ± 2.4 milliseconds window of point-cloud acquisition. For gaze estimation, PLPupil's 3D eye-model mode was used since it compensates for slippage[24]—the undesirable but common displacement of the head-mounted eye-trackers relative to the eye(s). The long-term accuracy for gaze mapping has been found to be maintained within 3.6° for the entire field of view of the Pico Flexx.[17] Pico Flexx records a point cloud, which contains the spatial scene information, with a visual field of 62° horizontal and 45° vertical/224 × 171pixels (for each pixel, a distance-vector is recorded with x, y, and z coordinates)/0.28° × 0.26° resolution, respectively. On average, five point clouds were acquired per second, with each at an acquisition time of approximately 30 milliseconds.[22] Before measurements were taken, the 3D-Eye-Tracker needed to be adjusted according to instructions from the manufacturer.[25] The field of view of the 3D-Eye-Tracker's scene camera was aligned with the anticipated range of the regions of interest for attentional capture during the study. With a habitual head position, the field of view of the Pico Flexx comprised the horizontal line of vision as an upper extreme and the direct view onto hand-held devices as a lower extreme (because they are positioned habitually much lower than the horizontal line of vision). The 3D-Eye-Tracker established a 3D model of each eye including nominal gaze direction from the eye-camera images.[24,26] These gaze direction estimates were aligned with the point cloud during a five-point calibration process as described previously.[17,27]

The objective foveal dioptric demand (OFDD) was calculated from a cluster of distance data, including a minimum of 13 pixels of the point cloud surrounding the gaze coordinates[17,28] and has been analyzed during times of high-resolution visual attention (i.e., during fixations).[29] Times of fixation were determined with Pupil Labs' fixation detector, a dispersion-based algorithm.[30] The dispersion angle threshold was 1.5°, and minimum and maximum durations were set to 80 milliseconds and 220 milliseconds, respectively, to match Pico Flexx's recording frequency and habitual fixation characteristics. Dioptric demand is presented in this study in the standard unit for refractive power, diopter D (1/m).

Objective and Subjective Dioptric Demand Estimation for Individual Visual Tasks

To establish foveal dioptric demand over time, near-work tasks were timed and categorized according to the modified Houston's NEAR survey definitions. The modified Houston's NEAR survey was adapted from the Sydney Myopia Study to incorporate knowledge from public health and psychology questionnaires.[14] This adaptation catered to the rising use of hand-held devices in assessments for near-work. Categories for near-work were: reading print, drawing, painting, writing, using hand-held devices, using a computer, playing board games or cards, watching tv, walking, playing games, dancing, and any other activity (with the option to "please specify").

For subjective foveal dioptric demand (SFDD), participants were encouraged to fill out a diary every 10 minutes, describing the task that they primarily engaged in during that period. The interval for making diary entries was chosen to balance between not interrupting habitual behaviors but also reflecting the activity level as precisely as possible. Each near-work task

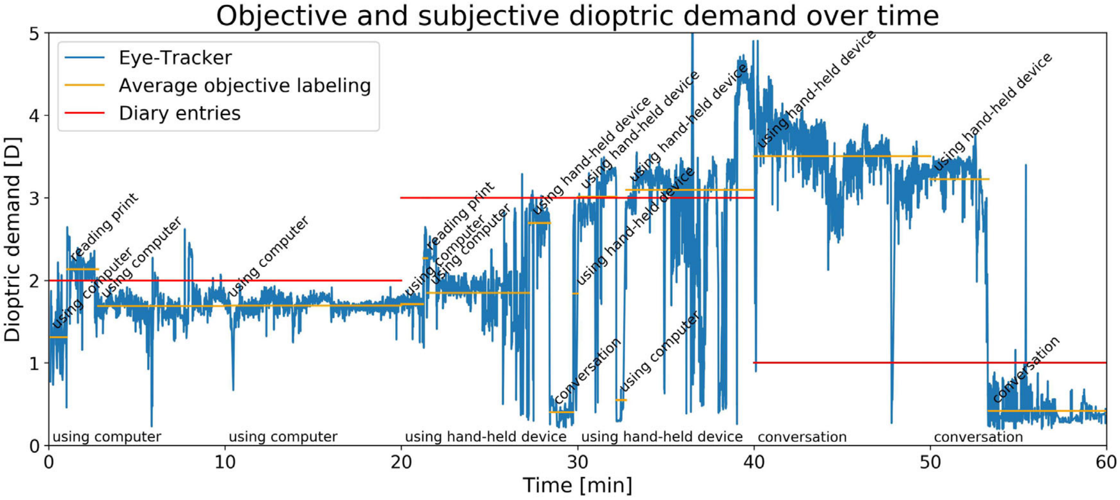

Figure 1. *Blue*, OFDD measured with 3D-Eye-Tracker. *Orange*, average of OFDD measured within objectively classified near-work task duration. *Red*, SFDD translated from diary entries according to standards described in Equation 1. Diary entries are shown at the bottom of the time series. Note: the frequent mismatch of OFDD measured by the 3D-Eye-Tracker and SFDD from diary entries.

is associated with an arbitrary dioptric value proposed by Zadnik et al.[7]

$$
\begin{aligned}
&\textit{Dioptric demand} = \\
&\quad 3\ x \ \textit{the duration of}\ (\textit{reading print} + \textit{drawing} \\
&\qquad + \textit{painting} + \textit{writing} + \textit{using hand-held devices}) \\
&\qquad + 2\ x \ \textit{the duration of}\ (\textit{using computers} \\
&\qquad + \textit{playing board games or cards}) \\
&\qquad + 1\ x \ \textit{the duration of}\ (\textit{watching tv}) \qquad (1)
\end{aligned}
$$

Unspecified near-work tasks were assessed individually. For example, the frequently mentioned near-work task “conversation” was estimated with a dioptric demand of 1 D. Other activities such as walking, playing games, and dancing were not classified as near-work (see Equation 1) and treated as times with no accommodative demand.

For the OFDD, P.W. classified the times of occurrence with labels of near-work tasks from the modified University of Houston near-work through visual inspection of the recordings from all participants. Fleeting variations of visual tasks (with durations of approximately 10 seconds or less) were discounted within prolonged periods of homogeneous near-work (e.g., fleeting moments of looking at a hand-held device while working on a computer for an extended period were not classified separately). For the continuous representation of time, interruptions of fixation needed to be accounted for (i.e., times of saccades, blinks, and invalid data). Therefore OFDD data were weighted in seconds. Furthermore, for each task conducted during the study, participants had to estimate the working distances to calculate individual dioptric demand estimations (individual dioptric demand value). Figure 1 presents sample data for SFDD and OFDD.

Estimation of the Dioptric Environment at and Peripherally to the Fovea

Objects from estimated gaze directions are projected onto the fovea, and the dioptric landscape surrounding the gaze direction is projected onto the retina periphery. Therefore the exact longitudinal position of the projection of the environment onto the retina can only be estimated due to unaccounted variables (e.g., accommodative lag). Therefore we estimate the diversity of the dioptric landscape solely with reference to the line of sight.[31] All depth maps from each point cloud were aligned with reference to corresponding gaze coordinates obtained from the temporally nearest gaze data (Fig. 2). Then, the dioptric map’s average was calculated. Hence, the presented

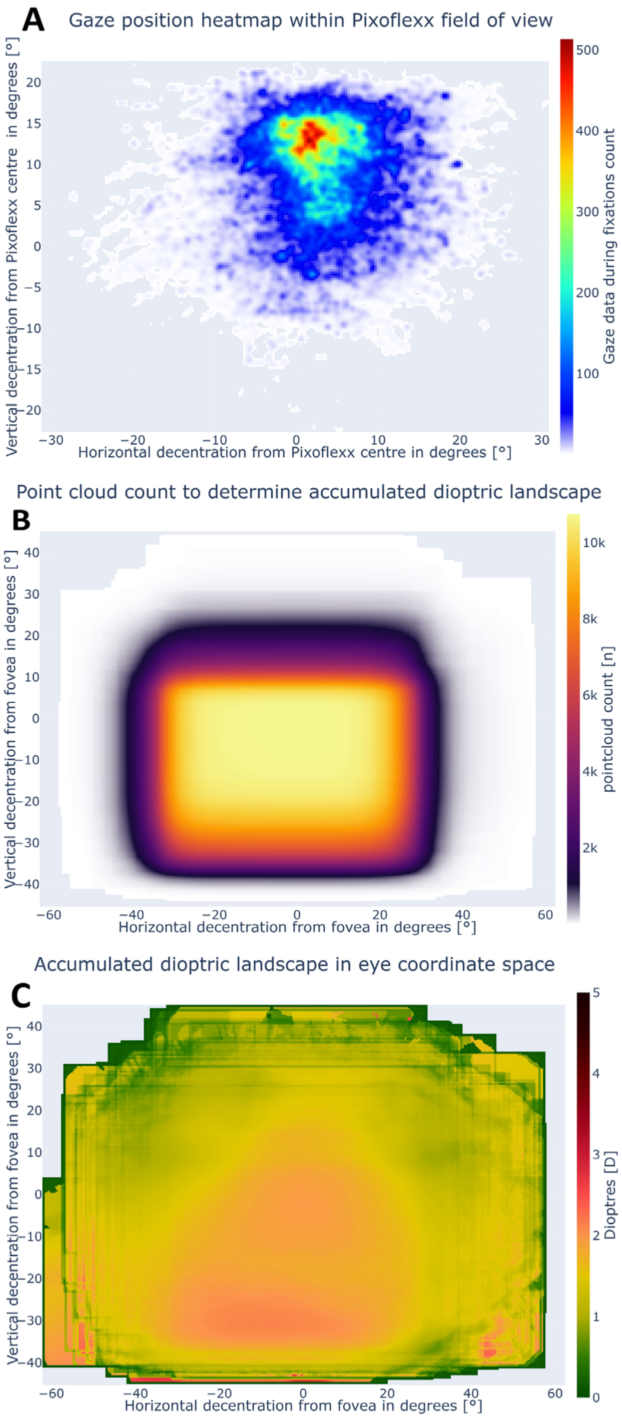

Figure 2. (**A**) Gaze data heatmap describes the measured gaze direction distribution during recording within the 3D-Eye-Tracker world camera’s field of view referenced to the origin. For this recording, most of the gaze directions have been recorded in the superior right quadrant. (**B**) Depth-map datapoint counting shows data counts used to calculate the average dioptric map. Note: x and y scales are adjusted to accommodate the optimal recording capability. Corresponding to the gaze data, most point-cloud data has been recorded in the bottom left quadrant. (**C**) Average of dioptric landscape as it appears to the eye during the time of recording. The line of sight is aligned at coordinates (0, 0), and head and eye-movements are compensated.

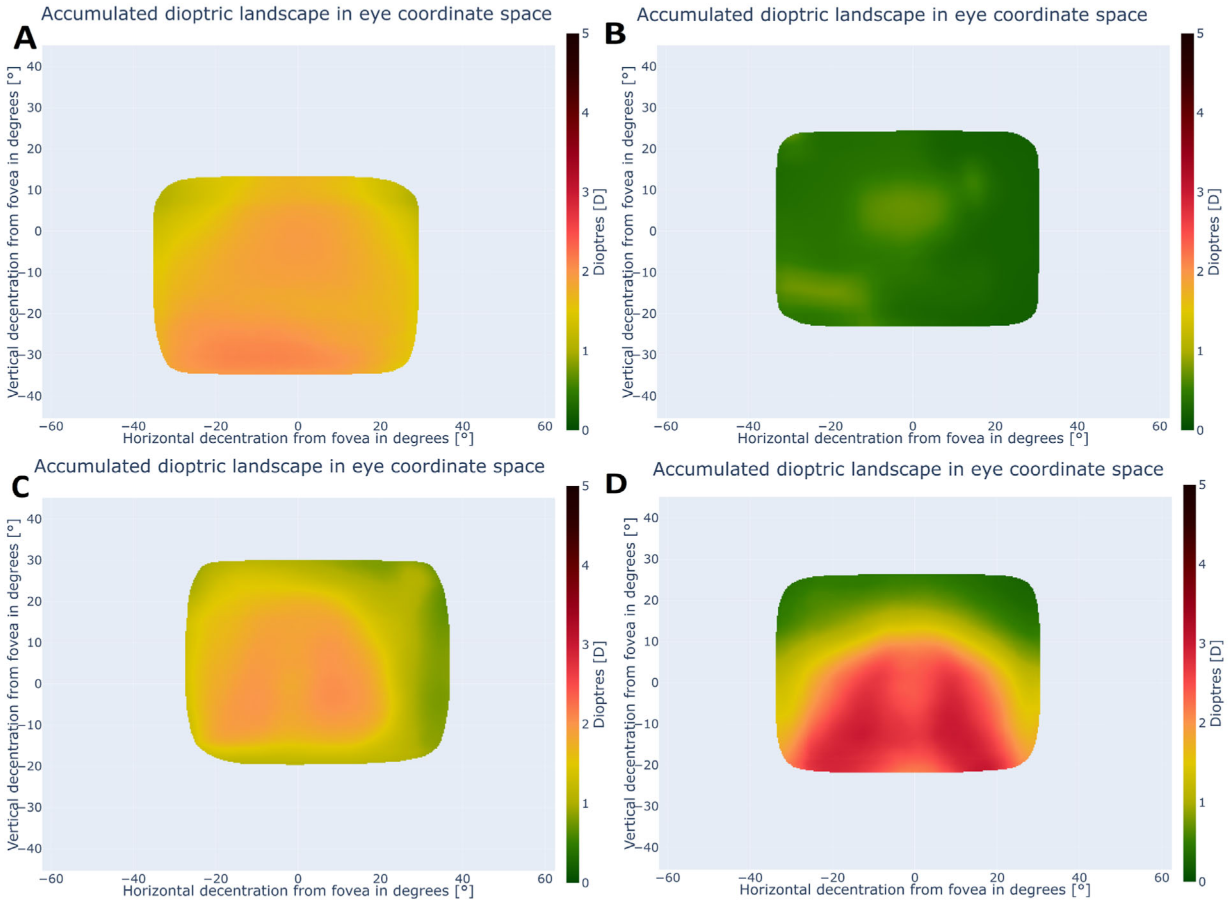

Figure 3. Sample figures of topographical dioptric demand for individual tasks representing a minimum of 40% of the total time (one hour). Tasks: (**A**) using a computer, (**B**) watching TV, (**C**) reading print, (**D**) using a hand-held device.

data show the averaged dioptric landscape and how it was exposed to the eye (Fig. 3). This data transformation is valid because head movements are compensated by using a head-mounted eye-tracker, and rotational eye-movements have been compensated by aligning the gaze positions between recorded dioptric landscapes.

Inter-participant field of view matching was orientated at the line of sight (e.g., gaze coordinates as displayed at coordinates 0,0). To maintain an accurate representation of the majority of time for each participant's one-hour recording, an arbitrary data inclusion threshold of 40% minimum was applied for inter-participant averaging.

General Conditions

To record solely habitual behaviors, participants were encouraged to proceed with their daily tasks for one hour while wearing the 3D-Eye-Tracker. To enable participants to proceed with their daily tasks, we arranged everyday environments (e.g., set up a TV, computer workspace, reading material, or let participants engage with their hand-held devices). Participants were free to walk around within the constraints of the data cable connection (USB3, approximately 6 m long) of the 3D-Eye-Tracker to the recording device. The connection might have reduced highly dynamic behaviors, such as engaging in physical exercise. No other restriction on behavior was imposed to maintain natural viewing habits.

The study was conducted in an open office environment (approximately 12 m × 5 m floor space) at the University of New South Wales in photopic lighting conditions. The room was illuminated with "cool white" fluorescent lights. Participants were encouraged to engage just in tasks that are safe and do not damage or compromise the 3D-Eye-Tracker or recording.

Study Protocol

Following the participant induction and consent, the 3D-Eye-Tracker was set up and calibrated. As reported previously, the one-hour observation study was embedded between gaze mapping accuracy tests from the validation study.[17] During the one-hour recording, participants were encouraged to proceed with their daily habitual tasks and to record their activities in the task diary.

Statistical Analyses

We used IBM SPSS Statistics 27 (IBM Inc., Armonk, NY, USA) for statistical data analyses. The near-work task classifications of OFDD data were assumed to be the new gold standard (ground truth data) because the associated near-work tasks have been classified by a third-party observer. The SFDD has been sampled to match time increments of OFDD and analyzed against ground truth data using a linear mixed model (LMM), which factored tasks as fixed effects and subject intercepts as random effects to account for within-subject–correlated repeat measurements. Post-hoc multiple comparisons were corrected for multiple comparisons using Bonferroni correction. The accumulated times of near-work tasks with subjective (SFDD) and objective (OFDD) labels have been evaluated for predictivity (Equation 2, Table 5), sensitivity (Equation 3, Table 6), and concordance (Equation 4, Table 7).

$$Predictivity = \frac{\text{time [s] spent on task}^{*}}{\text{total time [s]}\ \textit{spent on task}\ (SFDD)} \tag{2}$$

$$Sensitivity = \frac{\text{time [s] spent on task}^{*}}{\text{total time [s]}\ \textit{spent on task}\ (OFDD)} \tag{3}$$

$$Concordance = \frac{\text{time [s] spent on task}^{*}}{\text{total time [s]}\ (OFDD)} \tag{4}$$

*Time[s] spent on task (OFDD) indicates times that have been subjectively classified with a task during times of an objectively classified task.

Results

Participants

Approximately 16.7 hours (59,952 data points) acquired from 18 participants contained all prerequisite data and were valid for classification to near-work tasks (e.g., eye-tracking data and associated point-cloud data were available at times of fixational eye-movements). Twelve participants were emmetrope, three mild myopes, two mild hyperopes, and one high myope (Table 1). All non-emmetropes wore their habitual spherical contact lenses to suit the 3D-Eye-Tracking device.

Near-Work Tasks Estimations

The observed mean OFDD showed a range of 0.64°D (for conversation) up to 2.94°D (for using hand-held devices) (Table 2). The large number of data points leads to a marginalized standard error. Hence, the 95% confidence interval (95% CI) and the minimum and maximum values are not necessarily meaningful because the underlying distribution of data is more complex.

LMM estimation of the mean with Bonferroni correction found a significant difference in mean OFDD among all tasks, except between walking and watching TV ($P = .298$). Estimates in ascending order were conversation at 0.52 D (95% CI 0.36 D to 0.68 D), walking at 0.74 D (95% CI 0.57 D to 0.91 D), watching TV at 0.83 D (95% CI 0.66 D to 0.99 D), using computers at 1.74 D (95% CI 1.58 D to 1.91 D), reading print at 2.64 D (95% CI 0.48 D to 2.81 D) and using hand-held devices at 3.00 D (95% CI 2.84 D to 3.17 D) (Table 3). Most of the near-work tasks were statistically different from each other (Table 3). Clinically meaningful dioptric changes were beyond an absolute 0.25 D as commonly used as the smallest discriminator in optometric examinations.

Table 1. Summary Table of Demographic Characteristics of Study Participants

	17 Participants (Excluding One High Myope)			
	Average ± (One) Standard Deviation	Min	Max	High Myope
Age	32.3 ± 5.5 years	40	21	28 years
Gender	11 females/6 males			male
Prescription (D)	12 emmetropes/3 mild myopes/2 mild hyperopes			
OD sphere	−0.08 ± 0.77	−2.00	+1.25	−6.50
OD cylinder	−0.14 ± 0.23	−0.75	±0.00	−1.25
OS sphere	−0.02 ± 0.77	−1.75	+1.75	−7.00
OS cylinder	−0.16 ± 0.29	−1.00	±0.00	−1.25

Table 2. Observed Mean Summary of OFDD From 18 Participants (Approximately 16.7 Hours) That Were Labelled With Near-Work Tasks Weighted for Time in Seconds

	N Weighted for Time in Seconds	Mean	SD	SE	95% CI		Minimum	Maximum
					Lower Bound	Upper Bound		
Conversation	7319	0.64	0.38	0.00	0.63	0.65	0.30	2.27
Reading print	8027	2.70	0.78	0.01	2.69	2.72	1.31	4.61
Using computer	21,439	1.78	0.33	0.00	1.77	1.78	0.55	3.32
Using hand-held device	16,724	2.94	0.82	0.01	2.93	2.95	0.71	4.84
Walking	257	0.75	0.10	0.01	0.74	0.76	0.69	0.98
Watching TV	6186	0.70	0.13	0.00	0.70	0.70	0.59	2.67

The standard error yields only minor variations within the measurement but also might be attributed to the very large sample size.

Table 3. Linear Mixed Model Estimated Mean With Bonferroni Correction Shows Significant Differences Between Most Tasks

	Linear mixed model	Mean	SE	95% CI		Post Hoc (Bonferroni Correction)					
				Lower Bound	Upper Bound	Conversation	Reading Print	Using Computer	Using Hand-Held Device	Walking	Watching TV
Conversation	$P < .001$	0.52	0.08	0.36	0.68		.000*	.000*	.000*	.000	.000*
Reading print		2.64	0.08	2.48	2.81	.000*		.000*	.000*	.000*	.000*
Using computer		1.74	0.08	1.58	1.91	.000*	.000*		.000*	.000*	.000*
Using hand-held device		3.00	0.08	2.84	3.17	.000*	.000*	.000*		.000*	.000*
Walking		0.74	0.08	0.57	0.91	.000	.000*	.000*	.000*		.298
Watching TV		0.83	0.08	0.66	0.99	.000*	.000*	.000*	.000*	.298	

Most significant differences are also clinically meaningful.

[*] Clinically meaningful difference (>0.25 D) to LMM estimated mean.

Table 4. Standard Dioptric Demand Values (Zadnik et al., 1994) Used With the Modified Houston Near-Work Survey and Individual Dioptric Demand Values Derived From Participants' Self-Estimation of Working Distances

	LMM – 95% CI		Dioptric Demand Value		N Participants for Each Near-Work Task
	Lower Bound	Upper Bound	Standard	Individual	
Conversation	0.36	0.68	**1.0***,†	0.50‡	12
Reading print	2.48	2.81	**3.0***,†	2.56‡	14
Using computer	1.58	1.91	**2.0***,†	1.65‡	10
Using hand-held device	2.84	3.17	3.0‡	**2.78**†	16
Walking	0.57	0.91	**0.0***,†	**1.00***,†	3
Watching TV	0.66	0.99	**1.0**†	0.93‡	2

N Participants indicates the number of participants contributing data to each near-work task.

[*] Clinically meaningful difference (>0.25 D) to LMM estimated mean.

[†] Bold shows disagreement with LMM estimations.

[‡] Agreement with LMM (e.g., falls within the 95% confidence interval).

Generally, the mean OFDDs estimate a lower dioptric demand for the observed cohort than subjective classifications from the diary, except for walking (Table 4). Only the classification standard of using a hand-held device was within the 95% CI of the LMM, and only the classification standard of watching TV was within a clinically meaningful difference of 0.25 D relative to the LMM mean OFDD (Table 4). The mean individual dioptric demand value derived from participants' estimates of working distance showed more frequent agreement with the LMM estimates (Table 4). Walking showed the highest disagreement with a difference of 0.74 D. However, the task-associated dioptric demand was estimated for walking and watching TV based on three participants (257 data samples) and two participants (6186 data samples),

Table 5. Predictivity for Habitual Tasks From 16.7 Hours of Recordings Measured With Diaries Filled Every 10 Minutes

	Objective Label						
Diary Label	Conversation	Reading Print	Using Computer	Using Hand-Held Device	Walking	Watching TV	Total
Conversation	44.4%	4.1%	8.2%	43.3%	0.0%	0.0%	100.0%
Reading print	9.0%	84.0%	6.6%	0.5%	0.0%	0.0%	100.0%
Using computer	7.4%	9.9%	77.4%	5.2%	0.1%	0.0%	100.0%
Using hand-held device	9.4%	4.8%	2.7%	82.7%	0.4%	0.0%	100.0%
Walking	4.7%	66.8%	0.0%	0.0%	28.5%	0.0%	100.0%
Watching TV	1.0%	4.6%	0.0%	5.0%	0.0%	89.4%	100.0%
Total	11.5%	12.6%	36.4%	29.5%	0.4%	9.7%	100.0%

Table 6. Sensitivity for Habitual Tasks From 16.7 Hours of Recordings Measured With Diaries Filled Every 10 Minutes

	Objective Label						
Diary Label	Conversation	Reading Print	Using Computer	Using Hand-Held Device	Walking	Watching TV	Total
Conversation	43.6%	3.7%	2.5%	16.5%	0.0%	0.0%	11.3%
Reading print	5.0%	42.4%	1.1%	0.1%	0.0%	0.0%	6.3%
Using computer	28.5%	35.0%	94.4%	7.8%	5.8%	0.0%	44.4%
Using hand-held device	21.6%	10.0%	1.9%	73.7%	28.0%	0.0%	26.3%
Walking	0.4%	5.0%	0.0%	0.0%	66.1%	0.0%	0.9%
Watching TV	1.0%	3.9%	0.0%	1.8%	0.0%	100.0%	10.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

respectively. Hence, one would expect a low significant power and likely different values in other sample groups. Data from conversation, reading print, using a computer, and using a hand-held device were available from 10 or more participants (Table 4).

The predictivity of diary entries to reflect ground truth data varied between 28.5% for walking and 89.4% for watching TV (Table 5). Typical office-environment tasks were predicted correctly more often (e.g., reading print at 84%, using computers at 77%, and using hand-held devices at 83%; see Table 5). Conversation was a somewhat neglected near-work task, with just 44% of the time labeled correctly by the diary. Times of walking have been labeled with reading print for most of the time (67%) and was labeled correctly just 29% of the time by diary entries.

The sensitivity for modeling near-work tasks varied from 42% for reading print and 44% for conversation to 94% for using computers and 100% for watching TV. Walking at 66% and using hand-held devices at 73% showed an average sensitivity (Table 6).

The diary was found to correctly label task categories 76.4% of the time (Table 7). The majority of time was spent using computers (36%) and using hand-held devices (30%), followed by reading print (13%), conversation (12%), and watching TV (10%). The task of "walking" had a meager standard dioptric demand value but occurred scarcely and did not influence the overall dioptric demand value. For the most part, dioptric demand values of misidentified tasks canceled each other out after averaging. The SFDD estimate was found to be just 10.5% higher than the OFDD estimate.

The overall OFDD and SFDD across all participants show no significant difference with 1.96 D ± 0.62 D and 2.05 D ± 0.54 D (degrees of freedom (DF) = 17, $t = 2.1$, $P = .354$, paired-samples statistics, two-tailed), respectively. The OFDD and SFDD across all participants from data when objective and subjective task labels matched were found to be significantly different with 1.88 D ± 0.71 D and 2.09 D ± 0.60 D, respectively (DF = 17, $t = 2.1$, $P = .016$, paired-samples statistics, two-tailed). Also, OFDD and SFDD across all participants and all times showed a lower correlation coefficient than the OFDD and SFDD across all participants from data when

Table 7. Concordance for Habitual Tasks From 16.7 Hours of Recordings Measured With Diaries Filled Every 10 Minutes

	Objective Label						
Diary Label	Conversation	Reading Print	Using Computer	Using Hand-Held Device	Walking	Watching TV	Total
Conversation	5.0%	0.5%	0.9%	4.9%	0.0%	0.0%	11.3%
Reading print	0.6%	5.3%	0.4%	0.0%	0.0%	0.0%	6.3%
Using computer	3.3%	4.4%	34.4%	2.3%	0.0%	0.0%	44.4%
Using hand-held device	2.5%	1.3%	0.7%	21.7%	0.1%	0.0%	26.3%
Walking	0.0%	0.6%	0.0%	0.0%	0.3%	0.0%	0.9%
Watching TV	0.1%	0.5%	0.0%	0.5%	0.0%	9.7%	10.8%
Total	11.5%	12.6%	36.4%	29.5%	0.4%	9.7%	100.0%

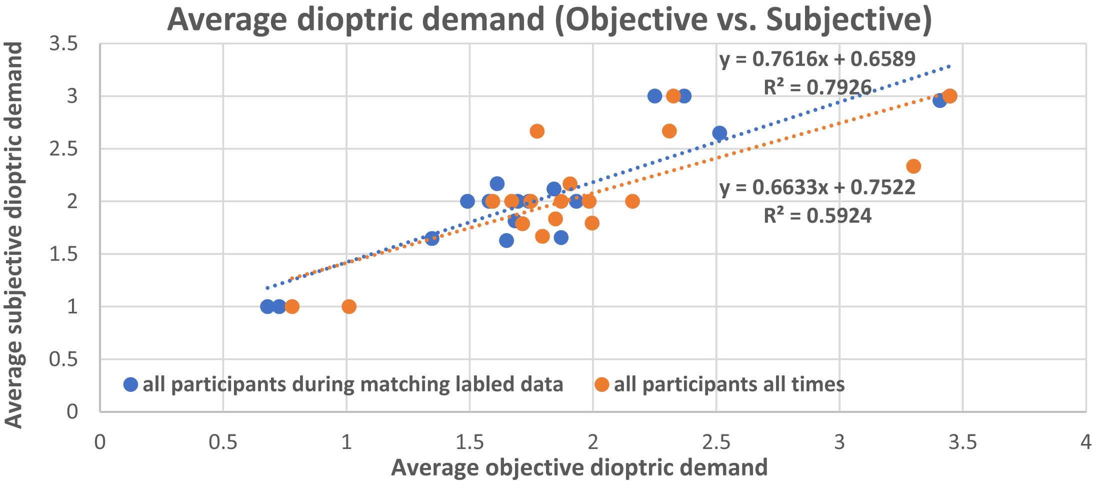

Figure 4. Average of OFDD and SFDD for all participants. *Blue*, considering just data when objective and subjective task labels matched. *Orange*, average dioptric demand data from all participants for all times.

objective and subjective task labels matched, $R^2 = 0.59$ and $R^2 = 0.79$, respectively (Fig. 4)

Dioptric Landscapes Exposed to the Eye at and Peripheral to the Fovea

Intra- and inter-participant gaze data was recorded at various coordinates within the Pico Flexx's field of view. Associated intra-participant dioptric demand maps were aligned at the central gaze coordinates (0, 0) for intra-participant averaging. Maps were then averaged across all 18 participants (Fig. 6). Figure 5 shows the inter-participant data distribution of available maps across the Pico Flexx's field of view (Fig. 5). A set of data from a minimum of five participants was set as the threshold for displaying dioptric map data (Fig. 6).

The inter-participant average of accumulated dioptric maps was estimated from 18 participants as presented to the human eye during habitual near-work conditions. In summary, habitual near-work

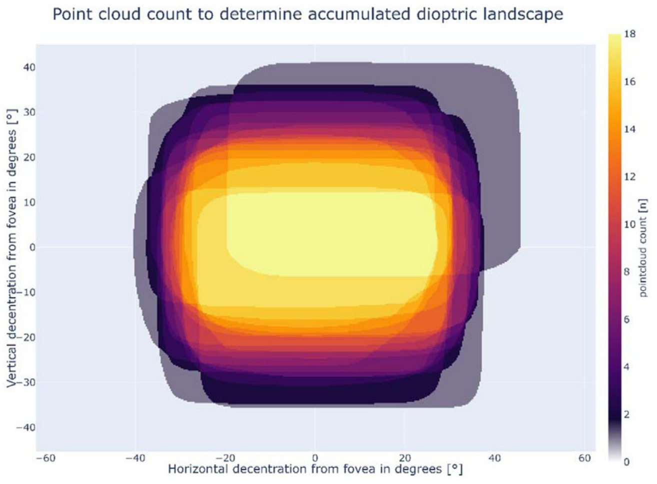

Figure 5. Inter-participant accumulated counts of point-cloud data representing collected data aligned at the gaze direction with coordinates (0, 0). To visualize the average of interparticipant accumulated dioptric demand map, a minimum of five data points was set as an inclusion threshold (Fig. 6)

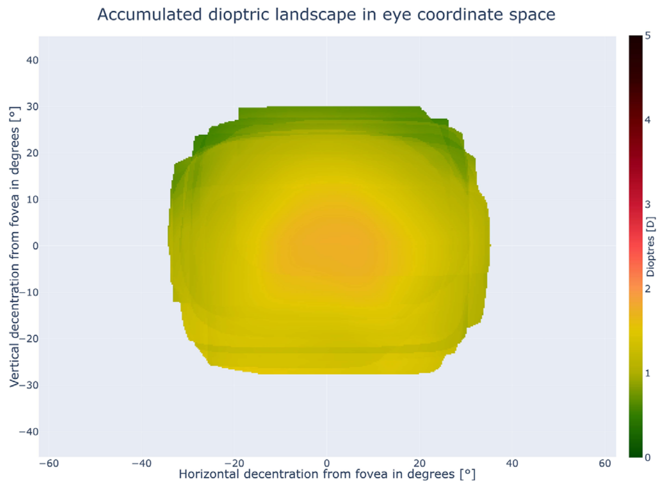

Figure 6. Averaged accumulated demand for all participants during near-work tasks. Data presented were averaged from a minimum of five participants.

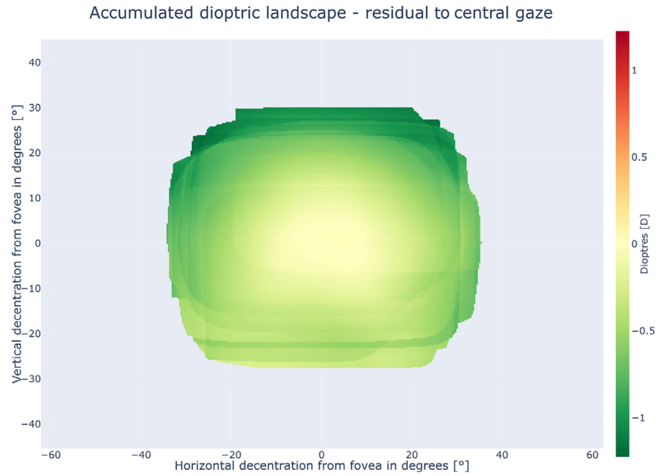

Figure 7. Residual of averaged dioptric demand from the line of sight displayed at gaze coordinates (0, 0) shows a decrease in demand toward the periphery.

tasks included: 11.5% conversations, 12.6% reading print, 36.4% using computers, 29.5% using a handheld device, 0.4% walking, and 9.7% watching TV. The central region (an approximately circular region with $r = 2.5^\circ$ around coordinates 0,0) relating to the exposure to the fovea was measured with the highest dioptric demand, approximately 1.74 ± 0.43 D (Fig. 6).

The residual from foveal dioptric demand indicates the pronounced foveal dioptric demand. Toward the periphery, the dioptric demand typically decreases horizontally by approximately 0.7 D, inferiorly by approximately 0.5 D, and superiorly by approximately 1 D (Fig. 7). Recorded data spanned approximately $\pm 30^\circ$ horizontally and $\pm 25^\circ$ vertically.

Discussion

Objective Versus Subjective Measurements of Near-Work

One of the main challenges for vision scientists is to establish tasks classifications within general visual behaviors that are descriptive and relevant for potential risk factors of myopia and distinctive enough to differentiate real effects between them. Currently, for the potential risk factor of excessive near-work, the literature is inconclusive and shows merely a weak link to predict myopia.[32] Therefore the main difficulty is the translation from habitual very short-term fixational eye-movements (50-200 ms) to classified tasks that are grouped by hours to generalize weekly or even longer patterns in behavior. The current gold standard (the near-work task diary) has been found to have a moderate correlation with questionnaires that are completed over a couple of days in a week.[33] However, the accuracy of translation from true individual near-work behaviors to diary entries has not been established, providing at best, poor accuracy and reliability, and at worst a potential systematic bias. Data presented from this study showed a 24% temporal disagreement between objective measures of near-work tasks, compared to subjective measures of near-work obtained by a diary with a task recording interval of 10 minutes. It may be reasonable to expect such disagreement to increase with an increase in diary data intervals (e.g., half-hourly instead of 10 minutes). Significant disagreement between objective measures and diary entries might be rooted in the short-term nature of human behaviors. Furthermore, the awareness and ability to recall certain human behaviors might be higher for some behaviors.

Interestingly, the overall OFDD and SFDD for all participants and all near-work tasks were not significantly different. In contrast, the overall OFDD and SFDD for all participants were significantly different when only data of matching near-work tasks were considered. But the correlation coefficient of the overall dioptric demand was only moderate and increased by 0.2 for the dioptric demand of near-work tasks with OFDD and SFDD matching labels to a relatively high coefficient ($R^2 = 0.79$). This finding supports previous reports of nonconformity in diary entries to reflect ground truth data on visual behaviors.[14,34] Hence, possible underlying distortion in the proportions of reported near-work activity might lead to invalid conclusions when individual near-work tasks are assessed.

This raises a possible concern because current questionnaires aiming to assess long-term visual behaviors (i.e., over a period of a year or even more) have assumed the validity of questionnaires by reference to the work of Saw et al.,[33] who evaluated near-work activities with 24-hour diaries (at half-hour intervals) and correlated them with an easy-to-use questionnaire. The questionnaire contained six different near-work tasks (1: Read or write in English; 2: Read or write in Chinese; 3, Watch television; 4: Play video games [e.g., Nintendo]; 5: Computer work or computer games; 6: Other close-up work activities, with "Please name the activity") for periods of time classified in hours per day: (a) on a weekday, (b) on a weekend, (c) before and during school examination time, and (d) during school holidays. They found a moderate intraclass correlation coefficient for "total weighted close-up work" of 0.50 (95% CI, 0.34–0.66) between questionnaires and the 24-hour diary.[35] It should be mentioned that the 'total weighted close-up work' comprised times that include approximately 6 hours per day from a school session, either measured or 'imputed'.[33] This estimate might have involved genuinely higher correlation estimates of near-work since a school activity schedule guided it. Considering the wake-sleep cycle, this 6-hour interval represents 35-40% of wake time and may influence the outcome measures considerably. Besides Saw et al., diary validation of questionnaires beyond reproducibility figures are challenging since they require continuous observation from a third-party. Furthermore, validating questionnaires might introduce repetition bias and therefore, might have been omitted frequently. Nevertheless, questionnaires are currently the only feasible option that can be distributed at a large scale and to stratified sample groups to establish long-term behaviors as risk factors that might contribute to myopia.

Dioptric Landscapes

Our study considers the appearance and magnitude of ecological dioptric landscapes as they are projected onto the retina over time. The data represents near-work in an office environment which poses significant dioptric demand. The myopia model proposed by Flitcroft[10] elaborates on a myopigenic scenario in which nearer objects introduce a hyperopic defocus for eyes looking at a distant target. Our empirical data suggests this proposed myopigenic scenario appears over just a fraction of the time (Figs. 6, 7). The dioptric landscape is less likely to present peripheral hyperopically defocused stimuli within the monitored field. The foveal dioptric demand is pronounced in comparison to dioptric demand in the periphery.

Our results were representative of a group with a diverse range of ages and sample tasks. However, human visual behaviors are much broader and more diverse than we can estimate with controlled studies. Myopia investigations often include younger cohorts, which likely have different near-work task preferences and associated dioptric landscapes. Instead of "reading print," children might prefer to play with toys or look at books. However, we also pointed out a more common scenario for children (i.e., the "use of a hand-held devices") (Fig. 3D). From the observations of the single task of "using hand-held device," the difference in dioptric demand centrally to peripherally (from the fovea to 20°, up to 30° peripherally with a higher magnitude inferiorly than superiorly) is much more extreme, estimated at 1 D to 2 D.

To estimate peripheral myopic defocus during times of the "using hand-held device," we need to consider accommodative lag and the decreasing working distance, the increasing ocular vergence, and a possible heterogeneity of accommodation across the visual field.[36–38] Accommodative lag has been found within ranges of 0.2 to 0.6 D, compensating partially for the peripheral demand.[36] The increasing ocular vergence causes an increasing mismatch of interocular retinal conjugate surfaces, as Gibaldi et al.[37] demonstrated, reducing the foveal peripheral binocular horopter (i.e., causing ipsilateral opposing peripheral defocus for the contralateral eye). Whereas image quality for the fovea and near-fovea periphery are similar, smaller amounts of dioptric variations across a 30° field have been found empirically during accommodation. Interpolating all three effects, the fovea periphery in the areas 20°and beyond is still exposed to myopic defocus. This finding poses a contradictory hypothetical mechanism between potential myopigenic risk factors; the higher dioptric demand of extreme near-work during the use of a hand-held device and the concomitant far peripheral myopic defocus.

Eye-Tracking Data Acquisition Challenges

Acquiring valid eye-tracking data requires a long list of prerequisites, from 3D-Eye-Tracker alignment to data selection. The Pico Flexx component of the 3D-Eye-Tracker has a small field of view relative to the possible field of fixation. Figure 5 shows dioptric demand maps counts from all participants that include the majority of gaze directions. Hence, it can be assumed that the majority of gaze directions are distributed within the range of ±20° up to ±30° for most visual tasks, which is comparable to previous findings.[39] The 3D-Eye-Tracker's scene camera must be adjusted carefully to accommodate the full range of potential eye-movements within the anticipated field of attention.

Conclusion

The foveal dioptric demand is an important measure to estimate the near-work that the eye experiences. The 3D-Eye-Tracker has demonstrated the feasibility of foveal and topographical dioptric demand measurement and recording over extended periods. There have been brief demonstrations of this capability with research devices, but this study reports the first estimates of unsupervised near-work in habitual office environments. Also, the estimation of dioptric landscapes has been derived from short-term data or single images, whereas this study is the first to demonstrate objective recording of the averaged dioptric landscape for extended periods with high temporal resolution.

The main challenge for vision scientists is to describe near-work because the translation from very short-term fixations (50-200 ms) to classified visual behaviors with homogeneous working distance needs to be quantifiable by surveys. Thus causal relations of individual visual behaviors on myopia onset and progression are much more difficult to establish because even minor reporting inaccuracies of general tasks could significantly change the near-work model's outcomes. Objective, quantitative measurements would simplify these models and would make data obtained more reliable and comparable.

Acknowledgments

The Brien Holden Vision Institute Limited, Sydney, Australia supported the study as part of Peter Wagner's postgraduate research.

Disclosure: **P. Wagner**, None; **A. Ho**, None; **J. Kim**, None

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