

# LIGHT EXPOSURE AND CHILDHOOD MYOPIA

There is evidence in many countries globally that the prevalence of myopia is on the rise. Advances in measurement technology now allow many environmental factors potentially associated with the development and progression of myopia to be quantified reliably and sampled densely. Our recent prospective longitudinal study of Australian schoolchildren, utilising wearable sensor technology has provided the first direct evidence of a significant relationship between personal ambient light exposure and eye growth in childhood; demonstrating that greater daily light exposure is associated with slower eye growth. These findings support the potential for interventions aimed at increasing daily outdoor light exposure, to reduce the development and progression of myopia in childhood.



## Associate Professor Scott A. Read

Director of Research,  
Contact Lens and Visual Optics Laboratory  
Queensland University of Technology,  
School of Optometry and Vision Science,  
Australia

Scott Read is an Associate Professor in the School of Optometry and Vision Science at the Queensland University of Technology, Brisbane, Australia. Since the award of his PhD in 2006, Scott has held a variety of research and academic positions, and has published over 60 peer-reviewed research papers, with the majority of this work focusing upon human myopia. He recently received the “Zeiss Young Investigator Award in Myopia Research” for his distinguished contributions to the myopia research field. He has also been an Associate Editor for *Clinical and Experimental Optometry* and acts as a Topical Associate Editor for *Optometry and Vision Science*.

Recent decades have seen a rapid rise in the prevalence of myopia in many developed nations around the world, with myopia prevalence levels greater than 90% reported in young populations in some developed Asian cities.<sup>1</sup> Using modelling based upon the current trends in myopia development and progression, a recent study predicted that around half of the world’s population will be myopic, and that approximately 1 billion people worldwide will have high myopia (5.00 D or more) by the year 2050.<sup>2</sup> The potential public health costs of these rising levels of myopia (and associated increase in high levels of myopia) are dramatic, given the known association between myopia and many sight threatening eye diseases, such as retinal detachment, glaucoma and retinal degenerations that have all been linked to myopia severity.<sup>3</sup>

This “myopia boom”<sup>4</sup> therefore provides a strong catalyst for the development of reliable methods to reduce both the development and progression of myopia in the population, in order to limit the detrimental visual and public health effects of increasing levels of myopia. The rapid increase in myopia prevalence in recent decades points firmly towards a role for environmental influences upon the development of myopia<sup>5</sup> however, the exact environmental factors involved in the regulation of eye growth and the development and progression of myopia are still not fully understood. A more comprehensive understanding of the various factors impacting upon the normal growth of

## KEYWORDS

Myopia, light exposure, eye growth, outdoor activity, refractive error.



“Our findings support the potential for interventions aimed at increasing daily outdoor light exposure, to reduce the development and progression of myopia in childhood.”

the eye and hence the development and progression of myopia in childhood is likely to be critical for the development of effective myopia control interventions.

#### A Move to Outdoors

Over the years, a range of different environmental factors have been proposed as potentially playing a role in human myopia development, with factors related to near-work, education and academic achievement being a major focus of many studies.<sup>6</sup> More recently, perhaps spurred on by the sometimes equivocal findings of studies examining the association between myopia and near work, a shift in the focus of refractive error research has occurred, with a move away from traditional near work measures and a broader focus on additional potential environmental factors (e.g. outdoor activities).<sup>7</sup> **Evidence has been emerging from both human epidemiological studies, and research with animals, that ambient light exposure may be an important additional environmental factor that plays a role in myopia.** Animal studies demonstrate that normal eye growth appears to be influenced by environmental light levels, since rearing young chickens in dim ambient light environments has been shown to result in more rapid eye growth and the development of more myopic refractive errors compared to rearing animals in bright ambient light conditions.<sup>8</sup> Similarly, exposure to bright ambient light conditions appears to block the development of experimental (form deprivation) myopia in chickens<sup>9</sup> and primates.<sup>10</sup> In humans, evidence of a potential role of light

exposure in myopia has arisen from a number of epidemiological studies that have shown that children who report spending greater time outdoors also exhibit a significantly lower prevalence and incidence of myopia compared to children reporting less daily outdoor time (see Sherwin *et al*<sup>11</sup> for a review of recent studies examining the association between myopia and outdoor activities). Childhood eye growth and myopia progression, is also known to vary according to the time of the year, with slower eye growth documented in summer months (where more environmental light and thus opportunities to spend time outdoors is available), and faster eye growth is documented in winter months (where less environmental light is available).<sup>12</sup>

Since spending time outdoors also typically involves exposure to high intensity outdoor light (often more than 100 times brighter than the typical indoor light levels), it has been hypothesised that the associations found between more outdoor activity and less myopia, support a potential role for light exposure in myopia development.<sup>13</sup> However, it is important to note that the majority of the previous studies examining outdoor activity and childhood myopia, (and studies of seasonal variations in childhood eye growth) have not objectively assessed the habitual ambient light levels experienced by the children in their studies. Instead, this previous work has relied upon questionnaires to quantify children’s activities and make estimates of their daily outdoor time, which does not provide an objec-

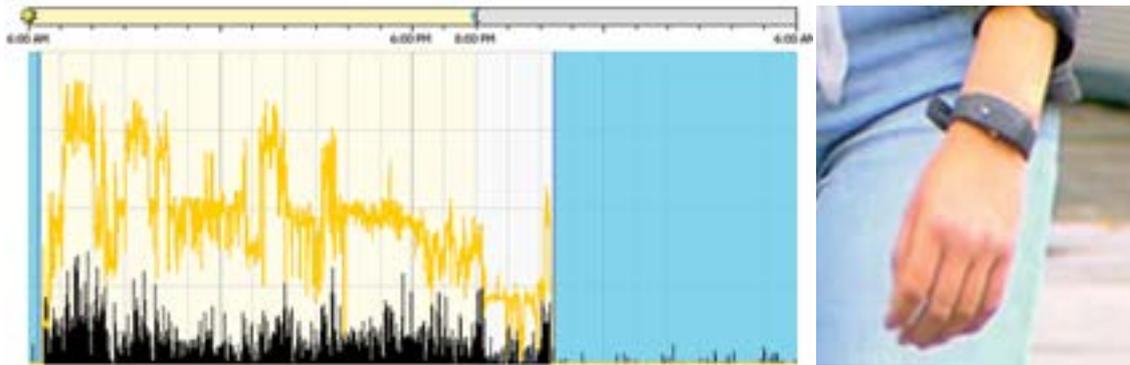


FIG.1| Example of light exposure and physical activity recordings from a representative ROAM study participant over a single 24 hour period (yellow line shows light exposure, and black bars show physical activity, blue shading indicates sleep period overnight), derived from the Actiwatch-2 devices worn on the non-dominant wrist, and programmed to record data every 30 seconds. Each child in the study wore the device continuously for two 14-day periods (separated by approximately 6 months) over the first 12 months of the ROAM study.

tive assessment of light exposure. It is difficult to know conclusively, based upon this previous work, whether the mechanism underlying the protective effects of outdoor activities is due to light exposure or another factor related to being outdoors (e.g. more physical activity, or less near focussing).

### Seeing the Light

Our recent research, taking advantage of wearable light sensor technology, has therefore aimed to improve our understanding of the factors underlying eye growth and myopia in childhood, by **examining for the first time, the relationship between objectively measured ambient light exposure, and children's eye growth.** The Role of Outdoor Activity in Myopia study (ROAM study) was an 18-month prospective longitudinal study of eye growth in myopic and non-myopic children. The experimental procedures and outcomes from the ROAM study have been reported in detail in a number of recent publications.<sup>14-16</sup> One hundred and one children, aged between 10 and 15 years of age, were enrolled in the study, including 41 myopic children (mean spherical equivalent refraction  $-2.39 \pm 1.51$  D) and 60 non-myopic children with refractive errors close

to emmetropia (mean spherical equivalent refraction of  $+0.35 \pm 0.31$  D). Each participant in the study had a series of ocular measurements, including measures of axial eye length collected every 6 months over the 18 month study period. Additionally, objective measurements of each child's individual ambient light exposure, and physical activity were also collected twice in the first twelve months of the study (approximately 6 months apart). These measures were collected using Actiwatch-2 devices (Philips Respironics, USA), a wrist watch sized device that contains a light sensor and an accelerometer, programmed to collect simultaneous measures of ambient light exposure and physical activity every 30-seconds of the day over each of the two 14-day periods of sensor wear (Figure 1). This represents over 80,000 individual measures of light exposure and physical activity from each child over the course of the study. These measures allowed us to examine the potential association between longitudinal changes in eye growth and children's habitual ambient light exposure and physical activity. Analysis of these densely sampled light exposure and physical activity data, revealed differences in the typical daily pattern of activities of the myopic and non-myopic

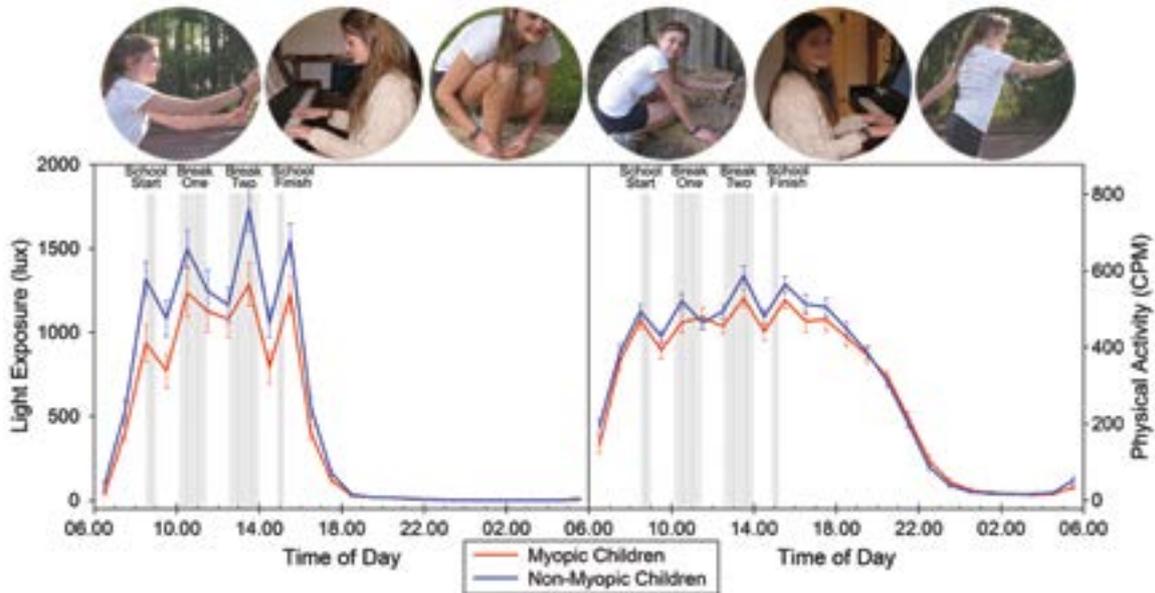


FIG.2] Average daily light exposure (left) and physical activity (right), averaged across each 60-minutes of the day, for the myopic (red line) and non-myopic (blue line) children in the ROAM study. Error bars represent the standard error of the mean. Vertical dashed lines indicate the mean timing of the school breaks and grey shading indicates the standard deviation of the break times.<sup>16</sup>

children in the study.<sup>14,15</sup> Although the daily variations in environmental light exposure and physical activity were observed to closely follow the pattern of children's typical school day (with peaks in activity and light exposure found before and after school and during lunch breaks in the school day), myopic children were found to exhibit significantly lower average daily light exposure compared to the non-myopic children, with the largest differences being found at times immediately before and after school and at lunchtime (Figure 2). This is indicative of less outdoor activities for the myopic children over these times. Although there were trends observed for the myopic children to also have slightly lower daily physical activity levels, differences associated with physical activity were not statistically significant.

The average axial eye growth observed in the myopic and non-myopic children in the study is illustrated in Figure 3. Analysis of these data revealed a number of statistically significant predictors of eye growth in this population of children, including the presence of myopia (where, as expected myopic children showed faster eye growth, indicative of myopia progression in this group), younger age

(where younger children showed more rapid eye growth than older children), and gender (where boys showed slightly faster eye growth than girls). Additionally, axial eye growth was also significantly associated with the children's average daily light exposure, with lower daily light exposure being associated with faster axial eye growth. To examine the relationship between light exposure and eye growth in more detail, the children in the study were further categorised (based upon a tertile split of their individual average daily light exposure levels, regardless of their refractive status) as being habitually exposed to low, moderate or high daily ambient light levels (Figure 4). Children habitually exposed to low daily ambient light levels (who on average were exposed to only 56 minutes of bright outdoor light per day) were found to exhibit significantly faster axial eye growth. These analyses included adjustments for refractive status, which suggests that these effects of light exposure on eye growth are occurring independent of refractive error. **Over the 18 months of the study, children exposed to low daily light levels, exhibited approximately 0.1 mm greater eye growth than children habitually exposed to moderate and high ambient light levels, which equates to a clinically significant ~0.3 D more myopic progression in refraction.**

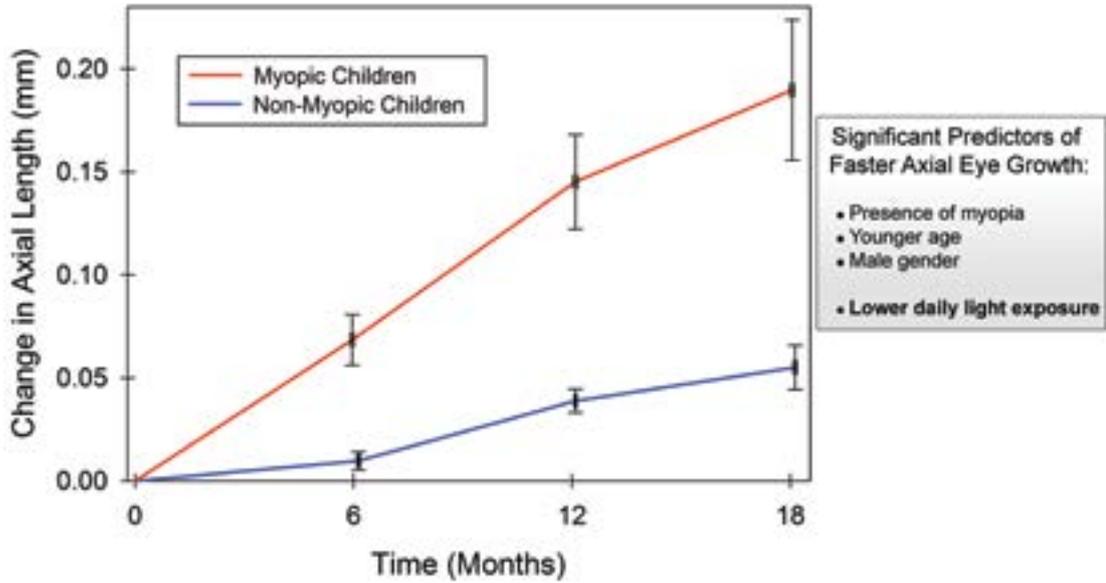


FIG.3] Average axial eye growth observed over the 18 month study in the myopic and non-myopic children. Error bars represent standard error of the mean. Linear mixed models analyses revealed that the presence of myopia, younger age, male gender and lower daily light exposure were all significantly associated with the rate of axial eye growth.<sup>15</sup>

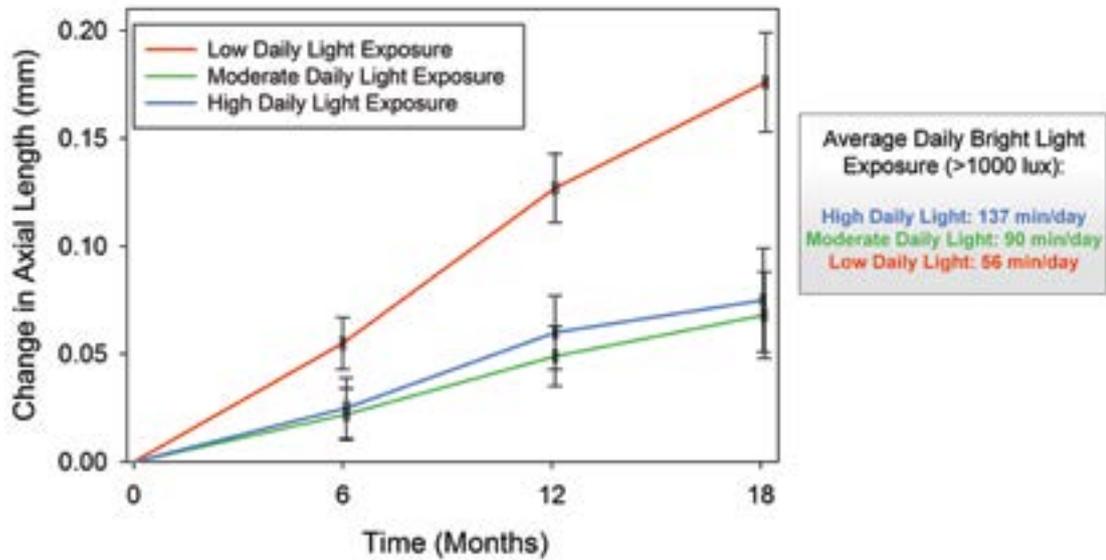


FIG.4] Average axial eye growth over the 18 month study after categorising children based upon their average daily light exposure as being habitually exposed to high, moderate or low ambient light levels (regardless of their refractive status). Children exposed to low daily light levels exhibited significantly faster eye growth. Error bars represent standard error of the mean.<sup>15</sup>



“These results provide us with the first direct evidence of a relationship between ambient light exposure and the rate of eye growth in childhood, and suggest that low light exposure is a risk factor for more rapid eye growth and hence myopia development and progression.”

The use of wearable sensor technology in this study provides important new insights into the mechanisms underlying the previously documented relationship between more myopia and less outdoor activities. Our findings support an important role for bright ambient light exposure in the protective effects of outdoor activities, and suggest that increased physical activity outdoors is not a key factor involved. These results provide us with the first direct evidence of a relationship between ambient light exposure and the rate of eye growth in childhood, and suggest that low light exposure is a risk factor for more rapid eye growth and hence myopia development and progression. **An important aspect of ambient light exposure as a risk factor for myopia is the fact that it is a modifiable environmental factor.** Children can modify their activities/behaviour in order to change their daily light exposure and potentially have an impact upon their rate of eye growth and hence risk for development and progression of myopia. These findings therefore support the potential for public health interventions aimed at increasing daily light exposure to reduce myopia development and progression in childhood.

#### Clinical Recommendations

While the ROAM study has provided new insights into the factors influencing eye growth in childhood, the study also provides us with empirical evidence regarding light exposure and eye growth that can be used to guide clinical recommendations to children and their parents. The children in the study categorised as habitually experiencing low daily light exposure, on average spent less than 60 minutes per day in bright outdoor light levels and also exhibited significantly faster eye growth than the other children in the study. This suggests that less than an hour of bright outdoor light exposure per day appears to predispose children to faster eye growth and hence risk for myopia development and progression. Significantly slower eye growth was seen in the children, who on average spent ~120 minutes per day exposed to bright outdoor light levels, **which suggests that increasing daily bright light exposure by an additional 60 minutes per day is likely to have an impact upon slowing axial eye growth (and hence reducing the risk of myopia development and progression).** This is supported by two recent studies<sup>17,18</sup> where interventions to increase children's outdoor time (by either 40 minutes or 80 minutes per day) were found to significantly reduce the incidence of myopia in populations of East Asian children.

## Conclusions

The work summarised in this article, helps to improve our understanding of the role of light exposure in the regulation of human eye growth and refractive error development and progression, and supports the potential for future myopia control interventions aiming to increase daily bright light exposure. However, more research is still needed to further our understanding of a range of aspects regarding light exposure and myopia. These factors include, the relative importance of the spectral composition of light, the optimum timing of light exposure and the specific intensity of light that is most important in the regulation of human eye growth. Additional knowledge from further research in this field may allow more targeted myopia control interventions to be developed in the future, which from the perspective of myopia control, looks to be bright. •

**Acknowledgements:** This work was supported by an Australian Research Council Discovery Early Career Research Award (DE120101434). I gratefully acknowledge my co-investigators Michael Collins and Stephen Vincent for their contributions to the work presented in this paper.

## REFERENCES

- Jung S-K, Lee JH, Kakizaki H, Jee D. Prevalence of myopia and its association with body stature and educational level in 19-year-old male conscripts in Seoul, South Korea. *Invest Ophthalmol Vis Sci.* 2012;53:5579-5583.
- Holden BA, Fricke TR, Wilson DA, Jong M, Naidoo KS, Sankaridurg P, Wong TY, Naduvilath TJ, Resnikoff S. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology.* 2016;123:1036-1042.
- Flitcroft DI. The complex interactions of retinal, optical and environmental factors in myopia aetiology. *Prog Retin Eye Res.* 2012;31:622-660.
- Dolgin E. The myopia boom. *Nature.* 2015;519: 276-278.
- Morgan IG, Rose K. How genetic is school myopia? *Prog Retin Eye Res.* 2005; 24:1-38.
- Morgan IG, Ohno-Matsui K, Saw S-M. Myopia. *The Lancet.* 2012;379:1739-1748.
- Mutti DO, Zadnik K. Has near work's star fallen? *Optom Vis Sci.* 2009; 86:76-78.
- Cohen Y, Belkin M, Yehezkel O, Solomon AS, Polat U. Dependency between light intensity and refractive development under light-dark cycles. *Exp Eye Res.* 2011;92:40-46.
- Ashby R, Ohlendorf A, Schaeffel F. The effect of ambient illuminance on the development of deprivation myopia in chicks. *Invest Ophthalmol Vis Sci.* 2009;50:5348-5354.
- Smith EL, Hung L-F, Huang J. Protective effects of high ambient lighting on the development of form deprivation myopia in rhesus monkeys. *Invest Ophthalmol Vis Sci.* 2012;53:421-428.
- Sherwin JC, Reacher MH, Keogh RH, Khawaja AP, Mackey DA, Foster PJ. The association between time spent outdoors and myopia in children and adolescents: a systematic review and meta-analysis. *Ophthalmology.* 2012;119:2141-2151.
- Donovan L, Sankaridurg P, Ho A, Chen X, Lin Z, Thomas V, Smith EL, Ge J, Holden B. Myopia progression in Chinese children is slower in summer than in winter. *Optom Vis Sci.* 2012;89:1196-1202.
- Rose KA, Morgan IG, Ip J, Kifley A, Huynh S, Smith W, Mitchell P. Outdoor activity reduces the prevalence of myopia in children. *Ophthalmology.* 2008;115: 1279-1285.
- Read SA, Collins MJ, Vincent SJ. Light exposure and physical activity in myopic and emmetropic children. *Optom Vis Sci.* 2014;91:330-341.
- Read SA, Collins MJ, Vincent SJ. Light exposure and eye growth in childhood. *Invest Ophthalmol Vis Sci.* 2015;56:3103-3112.
- Read SA. Ocular and environmental factors associated with eye growth in childhood. *Optom Vis Sci.* 2016; 93: 1031-1041.
- Wu P-C, Tsai C-L, Wu H-L, Yang Y-H, Kuo H-K. Outdoor activity during class recess reduces myopia onset and progression in schoolchildren. *Ophthalmology.* 2013;120:1080-1085.
- He M, Xiang F, Zeng Y, Mai J, Chen Q, Zhang J, Smith W, Rose K, Morgan IG. Effect of time spent outdoors at school on the development of myopia among children in China: A randomized clinical trial. *JAMA.* 2015;15:1142-1148.



## KEY TAKEAWAYS

- There is evidence of a rapid increase in myopia prevalence in recent decades in many developed countries.
- An improved understanding of the environmental factors underlying eye growth and myopia in childhood is crucial for developing effective myopia control interventions.
- Recent work utilising wearable sensors demonstrates the first direct evidence of a relationship between lower daily light exposure and faster axial eye growth.
- Less than 60 minutes of bright outdoor light exposure appears to be a risk factor for faster eye growth and hence myopia development and progression in childhood.
- These results support the potential for myopia control through increased daily light exposure (e.g. interventions to increase daily time outdoors).