Myopia and the Visual Environment

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Major environmental factors believed to play a role in eye growth regulation and the development and progression of childhood myopia provide clues as to how we can modify the environment and alter behaviours in an effort to protect against this potentially sight threatening ocular condition.

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Although it is widely accepted that there is some genetic involvement in the development and progression of myopia, the rapid increase observed in myopia prevalence in recent decades (with epidemic levels of myopia of up to 80-90 per cent seen in many developed East Asian cities), is highly suggestive of an important role for environmental factors in myopia genesis.[1]

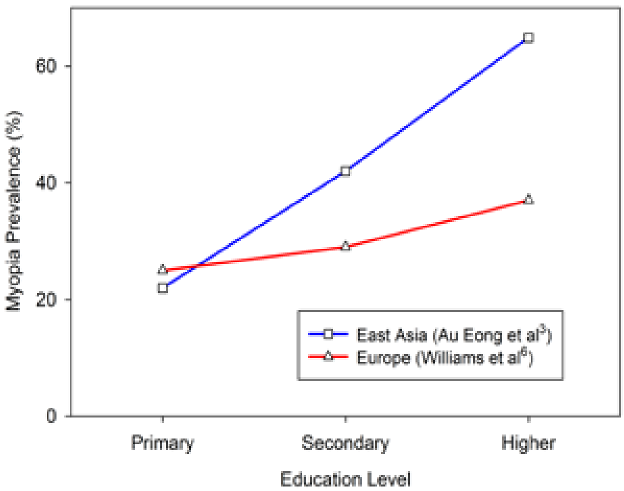
Research in both animals and humans, conducted in recent decades, has seen our understanding of the impact of the visual environment upon eye growth move forward substantially, with evidence for the involvement of a number of different environmental factors in myopia. Since many of these factors are modifiable, a better understanding of environmental impacts on myopia opens up the possibility for behavioural and public health interventions to change aspects of the visual environment with an aim to reduce the development and progression of myopia in the population.

Developing reliable interventions to protect against myopia is important given the well established association between increasing amounts of myopia and a range of sight threatening ocular pathologies (e.g. retinal detachment, glaucoma, myopic maculopathy). This article aims to provide an overview of three of the major environmental factors considered to play a role in eye growth regulation and the development and progression of childhood myopia.

MYOPIA, NEAR WORK AND EDUCATION

Myopia usually develops and progresses in childhood, and since this also coincides with the school years – where children are exposed to increasing levels of near work activities – reading and near work have long been considered to be potentially important environmental factors involved in myopia development.[2] Supporting a role for near work in myopia, there has been consistent evidence across a range of populations demonstrating a link between increased education and greater levels of myopia. A number of large population based studies have shown significant links between greater levels of education (either more years of schooling or higher educational level attained) and a higher prevalence of myopia (Figure 1).[3-6] In a report from the European eye epidemiology consortium (including data from more than 100,000 European adults), in middle-aged adults, the prevalence of myopia was found to be approximately double in those who had gone on to tertiary education compared to those leaving school before the age of 16.[6]

Figure 1: The association between myopia prevalence and education level from populations of East Asian[3] and European[6] adults.



Interestingly an interaction between genetics and education has also been reported from another large genetic study, with a substantially elevated risk of myopia observed in subjects exhibiting both a high level of education and a high genetic risk for myopia.[4] The odds of having myopia associated with a combination of increased genetic risk and high education level (odds ratio of 51.3) was found to be substantially higher than the sum of genetics (odds ratio of 7.2) and education (odds ratio of 6.1) as risks on their own. There is also evidence that increased myopia prevalence is associated with better academic performance in school (i.e. school grades)[7,8] and with attendance of academically selective schools[9,10] further suggesting that more intensive schooling represents a risk factor for myopia. Supporting this notion, Morgan and Rose[11] suggested an association between high myopia prevalence and countries where children exhibit high academic achievement and high participation in after school tutorial classes.

While the exact mechanism linking myopia with increased education is still not established, there is a range of evidence suggesting that ocular changes associated with near work tasks (e.g. reading) could predispose those children with high near work demands to increased myopia risk. The ocular effects of accommodation (and other biomechanical ocular changes associated with reading tasks such as downward gaze), are known to lead to a range of optical changes (e.g. increased higher order aberrations, lag of accommodation) that may provide an optical stimulus to increased eye growth and hence myopia development and progression,[12-14] given that animal research indicates exposure to hyperopic image blur can result in myopic eye growth.[15]

Furthermore, accommodation is also known to result in a number of short-term ocular biometric changes, such as a transient axial elongation and a thinning of the choroid.[16-18] Figure 2 illustrates the changes occurring in axial length and choroidal thickness with accommodation.[18] Interestingly, studies examining these ocular biometric changes with accommodation have shown that myopic subjects appear to take longer to recover from these transient changes than do emmetropic subjects, suggesting potential differences in the biomechanical properties of the myopic eye.[16,17] The structural ocular changes associated with accommodation could also provide a link between near work and myopia, given that choroidal thinning has been consistently associated with myopic eye growth in animal research.[19] A longitudinal study of choroidal thickness in childhood has also shown an association between choroidal thinning and more rapid axial eye growth, supporting a role for the choroid in the regulation of human eye growth.[20] Collectively, the cumulative effects of the optical and ocular biomechanical structural changes associated with near work could potentially predispose children engaged in long periods of intense close work to myopia development, however definitive evidence linking these changes with longer term myopia development and progression remains to be established. The fact that ocular changes associated with near work are transient does support the need for children to take regular breaks from intensive close work activities. Data from work[16-18] examining these changes suggests that breaks of ~5-10 minutes are required to allow these changes to dissipate.

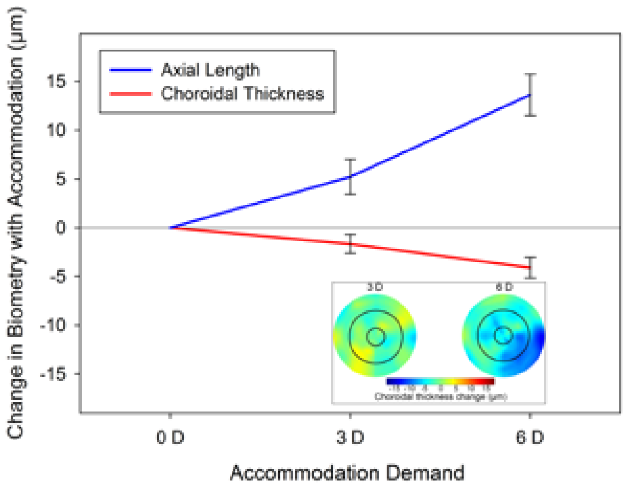
> "school-based outdoor interventions (aiming to increase outdoor time by 40–80 minutes a day) appear to significantly reduce the onset of childhood myopia..."

While the association between education and myopia could potentially be explained by a link between near work and myopia in childhood, research evidence linking patterns of near work activity with childhood myopia has not proven to be robust.[21] Although a number of studies, using questionnaires to quantify children's near work activities, have reported associations between increased near work activity in childhood and greater myopia,[9,22,23] other studies have failed to find such an association.[24-26] These inconsistencies in research findings relating near work with myopia could suggest the involvement of other factors aside from near work (e.g. lack of outdoor activity) in the association between myopia and education, or alternatively, it may suggest that more sophisticated methods are required to quantify the complex nature of children's behavioural patterns of near work activities. It is worth noting that studies examining the link between near work and myopia in childhood have relied primarily upon questionnaires to quantify children's patterns of near work, which can be subject to recall bias. Recently, new methods for assessing near work have been developed using wearable range finding sensors (attachable to a spectacle frame), that have the promise to provide continuous, objective, quantitative measures of near work behaviours in children.[27] Future research, using these detailed, objective methods of monitoring near work patterns, may assist to more definitively understand the role of near work in childhood myopia.

MYOPIA AND OUTDOOR ACTIVITY

The inconsistent findings from studies examining the link between near work and myopia have prompted researchers to turn attention towards the potential effects of additional environmental factors in myopia. This work has seen outdoor activity emerge in recent years as another important environmental factor associated with myopia.[28] A number of cross-sectional studies on children from a range of geographical locations have consistently reported a significant association between greater outdoor activity and a lower prevalence of myopia.[7,29] Data from the Sydney myopia study examining over 2,000 12 year old Sydney school children, suggested that children spending

Figure 2: The changes in axial length (top, blue line) and choroidal thickness (bottom, red line) occurring during a short duration 3 D and 6 D accommodation task.[18] Note the significant eye elongation and choroidal thinning that occurs at the higher accommodation demand. Inset illustrates the topographical choroidal thickness changes in the macular region occurring with 3 D and 6 D of accommodation (note that cool colours indicate a choroidal thinning with accommodation).



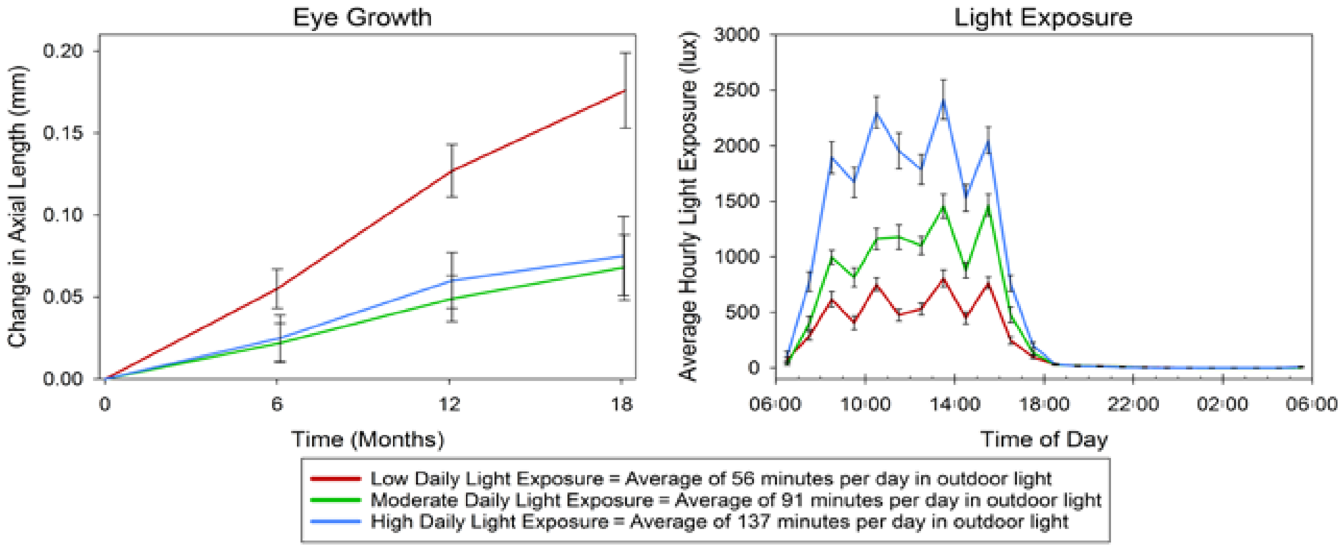


Figure 3: Axial eye growth in children habitually exposed to low (red line), moderate (green line) and high (blue line) daily light levels[41] (left). Note the significantly faster axial eye growth over an 18-month period in the children habitually exposed to lower average daily light levels. The average hourly daily light exposure of the children (collected using a wrist-worn light sensor worn for two, 14-day long periods by each child) in each of these three light exposure groupings is also illustrated (right).

more than 2.7 hours per day on outdoor activities exhibited a significantly lower risk of being myopic, even in those children performing high levels of nearwork.[29] Reports from longitudinal studies have also shown that greater outdoor activity in childhood appears to significantly slow the onset of myopia development.[30,31] The effects of outdoor activity on myopia progression however, has been less consistent. A number of studies have reported no significant association between outdoor time and myopia progression in childhood.[32,33] However, a small number of studies have reported a significant association between greater outdoor time in childhood and slower myopia progression.[23,34,35] Reports of seasonal variations in myopia progression, with slower progression in summer (where children have greater opportunity to spend time outdoors) compared to winter, also supports a potential protective effect of outdoor activities on myopia progression.[36,37]

In addition to observational studies examining the relationship between outdoor activity and myopia, a number of recent studies have also examined the impact upon myopia of interventions aimed at increasing children's outdoor time. These controlled trials have consistently shown that school-based outdoor interventions (aiming to increase outdoor time by 40-80 minutes a day) appear to significantly reduce the onset of childhood myopia compared to control groups.[38,39] He and colleagues[39] in a study of 1,903 Chinese children, found that children in the intervention group spending an extra 40 minutes per day on outdoor activities exhibited 9 per cent lower development of myopia over a three year period.

A recently completed outdoor intervention trial in Taiwan was reported at the 2017 International Myopia Conference. It showed that increased outdoor time at school recess each day significantly reduced both myopia onset and progression, in a population of 693 Taiwanese school children.[40] This recent finding of an outdoor intervention having an impact on myopia progression supports the potential for combining outdoor interventions with other myopia control interventions (e.g. spectacle, contact lens or pharmacological treatments) to further slow myopia progression.

> "even with hats and sunglasses in place, outdoor light intensities are still substantially higher than indoor light levels and are likely to be beneficial"

Although there is strong evidence that increased outdoor activity appears to protect against the development of myopia in childhood, the exact mechanism underlying these protective effects of outdoor exposure in the human eye are less well understood. Compared to indoor environments, outdoor activities typically involve exposure to higher light levels, greater physical activity, and may also involve less exposure to image blur and less near work activity. To examine some of these factors involved in the protective effects of outdoor activities, our research team recently conducted a study examining longitudinal changes in eye growth and objective measures of light exposure and physical activity (collected using wearable sensors) in a group of Australian children.[41] Findings from this study demonstrated that faster axial eye growth (and hence greater risk of myopia development and progression) was significantly associated with habitual exposure to low daily light levels; i.e. less daily exposure to bright outdoor light (Figure 3). Over an 18 month period, children habitually exposed to low amounts of outdoor light each day were found to exhibit ~0.1mm faster axial eye growth, which is equivalent to approximately 0.3 D more myopic shift in refractive error in this group. In contrast to the association with light exposure, eye growth did not exhibit a significant association with objective measures of physical activity. Our analyses also indicated that there was no significant effects of near work activities upon axial eye growth in this population, suggesting that the association between outdoor light exposure and axial eye growth wasn't simply due to less near work activity in those spending more time outdoors. These results suggest a role of outdoor light exposure (and not physical activity) in the protective effects of outdoor activities in childhood myopia. Our findings suggests that spending less than 60 minutes a day in outdoor light conditions is likely to increase the risk of myopia development, and that approximately two hours of outdoor light exposure per day is required to protect against myopia development. Although these findings support an important role for outdoor light exposure in myopia, further research is required to understand the optimum pattern of outdoor exposure required to protect against myopia, in terms of duration, frequency and daily timing, and also to determine whether exposure to certain wavelengths of light are more important than others.

Studies of experimental myopia in animals also support a role for light exposure in the protective effects of outdoor activity, since exposure to bright intensity light has been shown to prevent the development of experimental myopia in animals.[42,43] These studies also suggest that the mechanism underlying light mediated myopia prevention involves light induced release of retinal dopamine (a neurotransmitter known to inhibit ocular growth), since drugs that block the effects of dopamine also appear to block the protective effects of bright light on experimental myopia in animals.[44] Animal studies also suggest that the protective effects of bright light on myopia development do not require ultraviolet (UV) light exposure, since high intensity lights that do not include UV wavelengths still protect against the development of experimental myopia.[42]

In our study of light exposure in Australian children, the use of UV protection strategies (e.g. the use of hats and sunglasses) was not different between myopic and non-myopic children, and did not appear to be related to axial eye growth. From a clinical perspective, this suggests that the use of UV protection by children should still be encouraged when outdoors. The intensity of outdoor light also means that even with hats and sunglasses in place, outdoor light intensities are still substantially higher than indoor light levels and are likely to be beneficial.

MYOPIA AND THE URBAN ENVIRONMENT

A consistent finding in studies of childhood myopia has been that myopia prevalence tends to be significantly greater in children living in urban areas, compared to children living in rural areas.[45,46] In a population based study of teenage school children in China, He et al[44] reported a myopia prevalence of 50 per cent for children in urban regions compared to only 33 per cent for children in rural locations. There is also evidence that myopia progresses more rapidly in children living in urban environments[45,47] with the myopia progression of children in rural areas of China reported to be approximately half that of Chinese children living in urban environments.[45] While differences in the pattern of myopia prevalence and progression between urban and rural regions could be driven by differences in near work and/or outdoor activities between these regions, there is also the possibility that additional environmental factors associated with the urban living environment may further increase the risk of myopia in these locations.

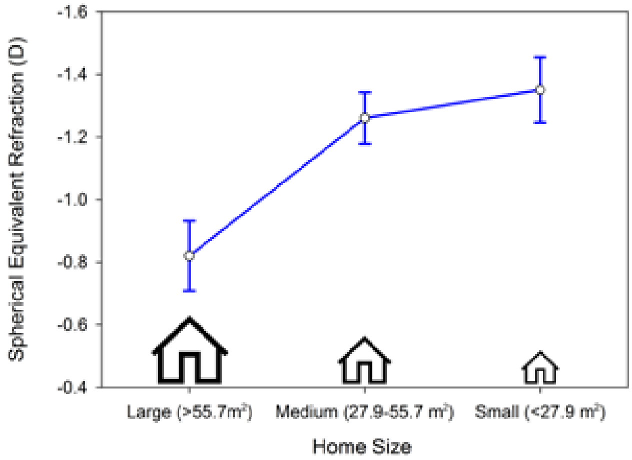


Figure 4: Association between home size and spherical equivalent refraction of children living in Hong Kong.[50] Note the significantly more myopic refractive error in children living in small homes, compared to those living in large homes.

Zhang and colleagues[48] examined factors associated with myopia in children in urban and rural China, and found that the population density in which the children were living was significantly associated with a greater prevalence of myopia, and this association appeared independent of near work and outdoor activities. Similarly, data from the Sydney Myopia study also reported an independent association between population density and myopia, with children living in inner city areas exhibiting a 2.2 times greater risk of myopia compared to children living in outer suburban areas.[49] Data from this study also indicated a significant association between housing type and myopia, with children living in apartments exhibiting a significantly higher prevalence of myopia (compared to children living in detached houses and terrace houses) after adjustment for confounders such as ethnicity, near work and outdoor activities. Recently, Choi and colleagues[50] also reported a significant association between population density and axial length and refractive error in a population of 1,075 children living in Hong Kong, with longer axial lengths and more myopic refractive errors associated with a higher population density. Interestingly, axial length and spherical equivalent refraction were also significantly associated with home size, with children living in smaller homes having significantly longer eyes and more myopic refractive errors compared to children living in larger homes (Figure 4). It was hypothesised that this association may be driven by an increased likelihood of exposure to hyperopic image blur in smaller confined living spaces.

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While these studies suggest that factors associated with the urban environment appear to be linked to increased myopia risk (independent of near work and outdoor activities) it is important to note that the majority of these studies are cross-sectional in nature, and so causality between these factors and myopia development and progression remains to be established. Longitudinal studies, comprehensively quantifying the environment and children's activities, are required to better understand these associations. Further research is also required to understand the mechanisms underlying these associations and to more precisely define the specific aspects of the urban environment that impact upon myopia. These findings however do appear to open up the possibility in the future for urban planning and design to potentially be modified in order to limit the myopiagenic effects of urban living environments.

CONCLUSIONS

In this article, evidence supporting a role for three major environmental factors in childhood myopia have been discussed. This evidence suggests that higher levels of education, greater urbanization and lower levels of outdoor activity are all linked to a greater risk of myopia development in childhood. The complexities of the visual system and the process of eye growth regulation, mean it is highly likely that it is the interaction between multiple environmental factors (with additional genetic contributions) that ultimately leads to myopia development in the human eye. An improved understanding of these major environmental factors (particularly through work exploiting technological developments allowing detailed objective monitoring of near work and outdoor activities), and their impact upon eye growth through future research, is likely to result in the development of new behavioural and public health modifications with promise for improved efficacy in protecting against the development and progression of myopia. Based upon current evidence, the most easily modifiable of the major environmental factors discussed is outdoor activity. Encouraging children to increase their outdoor exposure to ~2 hours per day (while encouraging UV protection) is likely to have a positive impact in limiting myopia development. mi

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