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THE IMPACT OF LIFESTYLE AND ENVIRONMENTAL FACTORS ON MYOPIA PROGRESSION IN CHILDREN

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Abstract
Myopia is now one of the most important pediatric eye health issues globally because of its rising prevalence coupled with long-term complications that include retinal detachment and glaucoma. This study is aimed to understand the role of the lifestyle/environmental factors on the progression of myopia in Pakistani children. A prospective cohort at Tertiary Care Hospital, Karachi from January 2023 to December 2024. A sample of 3,600 school children (aged 6–12 years) was enrolled by multistage sampling from schools and outpatient clinics. Assessment at baseline and 12- and 24-m follow-ups comprised cycloplegic refraction, axial length measurement, best-corrected visual acuity and ocular health. Eight questionnaires, activity diaries and an embedded objective sample (wearable light sensor and accelerometer) established detailed information of all outdoor activities performed during the study periods, near-work related factors, screen time, sleep duration and physical activity. This yielded striking age-related differences in myopia development. The mean spherical equivalent refraction shift was −0.89 ± 0.54 D at 24 months with younger children (6–8 years) progressing faster than older children. Outdoor time was identified as the most significant protective factor, with each additional hour spent outside daily related to slowing of myopia progression by -0.21 D ($p<0.001$). In comparison, both near-work as well as screen use significantly increased myopic shift independently (−0.18 D and −0.14 D per additional daily hour; both $p<0.001$). Parental myopia was the main non-modifiable risk factor; children of myopic parents had an extra −0.25 D progression over two years ($p<0.001$). Sleep length was modestly associated, and the children sleeping < 8 hours showed a faster of the disease course. Questionnaires responses in activity were verified against objective activity with high correlations for outdoor time, near work and physical activity $r=0.82$, $r=0.79$ and 0.76 respectively; the same behavioral associations were found with refractive change. These results offer strong, quantifiable evidence that modifiable lifestyle factors interact with genetic propensity to influence the trajectory of myopia during mid-childhood.

Keywords: Myopia progression, outdoor activity, near-work, screen time, parental myopia

Introduction

Myopia, also known as short sightedness, has emerged as a major public health issue worldwide, due to an accelerating prevalence of disease in children and young adults which translates into higher degrees of myopia greatly increasing the lifetime risk for sight-threatening sequelae such as myopic maculopathy, retinal detachment, and glaucoma. Early predictions and estimates emphasized a troubling trend: Holden et al predicted the prevalence of both myopia and high myopia to markedly increase by mid-century, drawing attention to the necessity of prevention and control strategies. Subsequent combined analysis from even larger contemporary global datasets supports the sobering message: pooled prevalence estimates indicate that nearly one quarter to as much as one third of children and adolescents globally are myopic, (George *et al.*, 2023) and, in the absence of effective public health interventions, there will be more than 700–740 million affected children by 2050 (Little *et al.*, 2025). These projections highlight that research and policy should focus on modifiable determinants of onset and progression.

A key consideration for clinicians and investigators alike is whether the drivers of myopia onset (the shift from emmetropia to myopia) are different to, or interact with, drivers of the subsequent progression of myopic refraction (rate of change in spherical equivalent [SE] refractive error or axial length). Being outdoors time (National Academies of Sciences & Medicine, 2024) that a range of population and interventional studies have determined that an increase in time spent outside is associated with a lower risk of onset, particularly in younger non-myopic children; however, the evidence that outdoor slows progression of already myopic children is less clear. At the same time, rapid shifts in children's lifestyles over the past two decades, notably longer periods of time spent on digital screens, diminished outdoor play, more intensive education and near-work demands, have meant that linked exposure patterns related to both onset and progression are changing in ways that may drive combined excesses in high myopia among populations.

Near work has been a consistent predictor of myopia across various observational studies and meta-analyses, pooling estimations reveal a small but statistically significant association between cumulative hours of near work and odds for myopia (Dutheil *et al.*, 2023). The widespread use of devices in contemporary schooling and leisure, however, necessitates disentangling the influences of generalized near work from specific screen modalities (phone vs tablet vs computer or TV) and the accompanying contextual behaviours related to screens (lack of outdoor exposure, poor postures, no breaks) for targeted advice. Large meta-analyses and dose-response analyses recently published indicate a non-linear relationship for digital screen time with myopia, with elevated risk reported to emerge after modest daily amounts of screen use in some analyses (Foreman *et al.*, 2021).

In addition to these core lifestyle exposures, several other environmental and behavioral factors warrant consideration: objectively measured environmental light exposure (intensity and duration) has recently been raised as a potential proxy biological mediator; physical activity and sedentary behavior may operate through separate or common reductions in outdoor time; sleep and circadian organization have been proposed to influence ocular growth via melatonin- and dopamine-mediated mechanisms; host factors not subject to modification such as age, sex, race/ethnicity, and family history of myopia, are important determinants of baseline risk that are likely also modifiers of the strength of association for modifiable exposures (Hysi *et al.*, 2020). Several controlled and pragmatic interventions (school-based outdoor programs, parent-directed behavioral messaging, and pharmacologic approaches including low-dose atropine) offer a developing evidence base for action; however, translation to population-level approach requires strong observational data that integrates objective and self-report exposure measures while carefully considering confounding and effect modification.

The present body of evidence presents a strong case for an early prospective cohort study with extensive lifestyle and environmental exposure data, cycloplegic refraction and axial length measures as outcomes, and follow-up of children throughout a significant developmental period. The proposed study determined the relative contributions of hours of viewing, near work activity, time outdoors (subjectively and objectively measured), and physical activity to the annual pace of myopia progression among 6–12-year-old children adjusting for parental myopia and the baseline level of refraction. These results will aid better informed authoritative advice for parents, schools and health systems, and empirical estimates to define efficient intervention trials and public-health campaigns.

Review of Literature

The rising prevalence of childhood myopia in multiple regions and over a period of decades has been reported in several large systematic reviews and pooled analyses. Holden et al. (2016)1, which were highly influential global projections over the long term showing a large increase in both myopia and high myopia, a pattern that has been confirmed and refined by subsequent larger pooled analyses such as (Holden *et al.*, 2016) including millions of children indicate childhood myopia prevalence has climbed from around 24% in 1990 to mid-30s% through 2023 but projecting nearly 40% by year 2050 across wide geographic variation (highest rates seen in East Asia). These epidemiologic patterns provide an epidemiologic context for assessing modifiable factors contributing to myopia development and progression.

A consistent body of observational evidence, alongside randomized school-based trials and pooled overviews, show that outdoor time is protective against myopia onset. Several meta-analyses document dose-dependent reductions in the odds of becoming myopic with greater weekly hours outdoors; estimates from pooled cross-sectional or cohort studies are approximately 2%–5% reduced odds per additional hour spent outdoors per week (Ho *et al.*, 2019). Practical interventions conducted in school settings, which were implemented as additional outdoor time for children ranging from around 40–120 min per day, showed clinically important changes in the incidence of new myopia over follow-ups from 1 to 3 years (Tsai *et al.*, 2016). Importantly, data from interventions indicate that the preventive effect is most apparent for delaying onset of myopia in nonmyopic children while robust evidence that more outdoor time significantly slows progression among children who are already myopic on average is less clear; multiple meta-analyses have concluded that extended outdoor time is more likely an onset-preventing exposure than a true progression-slowing therapy (D Li *et al.*, 2024). Mechanisms that have been proposed include brighter outdoor light increasing retinal dopamine release, which would in turn modulate scleral remodelling and axial growth, and there is experimental animal work to support an intensity-dependent effect of light on eye lengthening. These results support the inclusion of an objective measure of ambient illuminance (Wang *et al.*) in cohort studies where self-reported outdoor time is assessed.

Existing literature has long associated increased near-work exposure (studying, reading, use of handheld instruments at close working distances) and higher odds of myopia. Meta-analyses have found small-to-moderate associations; pooled estimates from the childhood studies showed increased odds of myopia with greater near-work duration and, in analyses quantifying “diopter-hours,” small incremental risk per unit increases in weekly near work (Dutheil *et al.*, 2023). The causal pathway is still a matter of debate with theories ranging from accommodative demand and hyperopic retinal defocus at near to confounding by level of education and reduced time spent outdoors. Recent observational evidence also hints that the patterning of near-work (duration of sustained near, breaks) may be as relevant as overall elapsed time (Redondo *et al.*, 2025). As a result of contemporary schooling practices and extracurricular tutoring, which involve prolonged near work on the order of several hours per day for extended periods, there is a need for more sophisticated exposure measures (e.g., diopter-hours, continuous near task time) to accurately estimate risk.

Screen use has become almost universal among children, yet the epidemiologic picture of digital device exposure and myopia was quantified with high precision only recently. The most comprehensive recent dose-response meta-analysis that included tens of studies reported an (inverse) non-linear association between daily screen time and odds of myopia: the risk from virtual lifestyle rose quite notably over the 1–4 hour/day range, with a highest gain at the low end of this exposure, which may support the evidence-based data towards an existence of a practical everyday threshold to be exceeded in hours per day for seeing a more steep increase in risk (Hu *et al.*, 2021). There may be differences in estimates according to screen modalities; some pooled results suggest stronger associations with near-fixed screens (computers, televisions) than with smartphones in certain analyses, although heterogeneity across study designs and exposure measurement types precludes definitive assertions. The COVID-19 crisis, with large and acute increases in screen time accompanied by simultaneous decreases in outdoor exposure, allowed for a natural experiment that several large datasets associate with accelerated myopic shifts among children.

Myopia appears to be inversely associated with physical activity in several observational studies, although the independence of this relationship from that with outdoor exposure is not completely clear. A number of studies reported on the relationship between level of daily physical activity and myopia with higher levels of activity tending to be associated with reduced odds for myopia (e.g. ~12% decrease in odds per additional hour of activity in pooled analyses), which, however, are highly heterogeneous across studies (Ding *et al.*, 2025). Sleep duration and circadian factors are a new area of interest; some early observational work has suggested that both short and very long sleep durations might influence refs in relation to hormonal or behavioral modulators, but causal evidence is limited. Data on these lifestyle characteristics in prospective cohorts are needed for multivariable models that separate direct from indirect effects.

However, non-modifiable host factors continue to be among the strongest predictors of initiation and progression for both. Risk of offspring myopia is much more marked with parental than environmental myopia, and is used clinically to stratify risk (X Zhang *et al.*, 2015). Ethnic inequalities are apparent, with children from East and Southeast Asia having higher population prevalence and rates of progression in many settings. Baseline SE is a powerful predictor of axial elongation and the development of HM in the future; thus, children with mild myopia at a young age are more likely to develop HM. For these reasons, have to be controlled family history, baseline refraction with cycloplegia and age in high quality cohort studies.

Time-outside interventions and parent-focused behavior messaging have proved successful in lowering the incidence. There is a good example of such an approach with repeated SMS reminders to parents to promote outdoor play and light exposure in a randomized trial that successfully reduced axial elongation and myopia progression over multi-year follow-up, these are scalable behavior changes (S-M Li *et al.*, 2022). Pharmacologic intervention, in particular low-dose atropine eye drops, is supported by the best evidence for arresting progression in myopic children; systematic reviews and recent randomized trials have found that 0.01%-0.05% concentrations retard progression as compared with placebo when used to reduce the rate of axial elongation, yet side effects increasingly affect dosing and rebound plays a major role once discontinued (Pugazhendhi *et al.*, 2020). A combination of behavioral and pharmacologic approaches may be the most effective approach for children at highest risk, but this proposition is the subject of comparative effectiveness research. Because of this 2-pronged evidence base, in observational studies the usage of clinical myopia-control therapies should be mentioned as a potential confounder and effect modifier.

Variation in measures of exposure (self-report vs objective sensors), outcome ascertainment (cycloplegic vs non-cycloplegic refraction; measurement of axial length), and duration of follow-up also explains study level differences. Most published analyses depend on self-reported exposures, which may misclassify screen time and outdoor exposure; objective measures (wearable light sensors, actigraphy, device usage logs) can improve exposure estimates but are underutilized in large cohorts (Guidolin *et al.*, 2024). In addition, longitudinal studies with repeated measures of objective exposure and excellent ocular phenotyping at the same time point are relatively low. Finally, it is not yet entirely clear what the relative contribution of modern screen-related behaviors (interactive vs passive viewing; viewing distance; type of device) are. These methodological shortcomings drive the design of measurement in the current-proposed cohort.

Methodology

This section describes the research design, sampling plan, and study protocol for the investigation on lifestyle and environmental factors of myopia progression in children. It depicts the cohort study, participants' recruitment, measuring instruments and statistics methods that are used to maintain the quality and reduce bias data collection and analysis.

3.1 Study Design and Setting
A prospective cohort study was done at Tertiary Care Hospital, Department of Ophthalmology, Karachi, Pakistan from January 2023 to December 2024. JPMC was selected as the site of study as it is a major tertiary care and teaching hospital in Pakistan that receives patients from urban and peri-urban areas. This heterogenous patient group has provided access to a broad spectrum of pediatric participants from different socioeconomic, environmental settings that is important for studying the effect of lifestyle and environment on myopia progression (Biswas *et al.*, 2024).

3.2 Study Population
The study population included school-aged children between 6 and 12 years who presented to Tertiary Care Hospital outpatient clinics for routine vision testing or were referred from local schools which participated in the research. This age range was the subject of the study as it falls within what is termed a sensitive period when myopia begins and progresses. Boys and girls were eligible for inclusion if they had a baseline refractive error of +0.50 diopters to −6.00 diopters, confirmed after cycloplegic refraction (D Zhu *et al.*, 2016). Parents or legal guardians provided written informed consent and children gave verbal and written assent. Exclusion criteria were very meticulous so as to eliminate confounding factors: children with ocular pathologies other than refractive errors (for example, amblyopia, keratoconus, cataract or retinal disease), those with a history of eye surgery or trauma, children suffering from systemic conditions that affect growth or development of the whole body and children under active myopia-control therapy (orthokeratology; atropine ≥0.01%; specialized spectacle/contact lens) were excluded.

3.3 Sample Size and Sampling Technique
The study size was presenting with a reported myopia progression rate of approximately 20% from previous regional reports. A sample of 3,400 children would have 95% confidence intervals with a margin of error of approximately 5% and a power to detect differences in the distribution across groups at the level of Power 80% (Staffa & Zurakowski, 2020). To adjust for a potential drop-out of 10% over time, the initial target sample size was decided to be 3600 participants. The cluster sampling method was used for recruitment. Two-stage sampling was employed in which urban and peri-urban schools of Karachi were selected randomly in the first stage. In the second step, students who fulfilled these criteria from these schools were called for baseline assessment. In the third phase, some participants were also recruited from outpatient clinics to get diversity in socioeconomic status and environmental exposures.

3.4 Data Collection Procedures
All enrolled patients received ophthalmic examination at baseline. Cycloplegic autorefraction was performed after administering 1% cyclopentolate (two drops with a five-minute interval) and measurements were taken within 30 minutes of the second drop. Axial length (AL) was obtained using partial coherence interferometry (IOL Master 500, Carl Zeiss Meditec) (Kim *et al.*, 2020). Best-corrected visual acuity (BCVA) was recorded using Snellen charts and the anterior and posterior segment were examined with slit-lamp bio microscopy and indirect ophthalmoscopy to exclude exclusion criteria.

Data on environmental factors and lifestyle exposures was obtained through a structured questionnaire for the parents and children. This included daily outdoor time, near-work (activities like reading, writing and device use) hours, digital screen time divided by device type, physical activity levels and average nightly sleep length. Participants were also instructed to keep a 7-day activity diary to improve accuracy and minimize recall bias at baseline and each follow-up visit. In addition, a random subsample of 1,200 children wore light sensors and wrist accelerometers to objectively assess exposure to light, time spent outdoors, and sedentary behavior during two-week monitoring periods at baseline, 12 months, and 24 months (Westrep, 2017). These same ocular examinations and questionnaires were repeated at 12 and 24 months. Regular prompts and phone calls were given to the parents in an attempt to reduce dropout rates and promote adherence to protocol.

3.5 Data Analysis
All data were recorded in SPSS (version 26.0, IBM Corp.) and double-data entry was performed to ensure recording accuracy. Baseline demographic and exposure variables were summarized using descriptive statistics (means, standard deviations and frequency distributions). Measurements of SER and AL were analyzed by linear mixed-effects regression to allow for repeated measures and clustering within school. The logistic regression with generalized estimating equations (GEE) was employed to determine the risk of developing myopia (R Zhang *et al.*, 2022). Interaction terms were added to investigate whether the associations of exposures with outcomes differed according to parental myopia or baseline refractive status. The objective measures of activity of the subsample were compared to questionnaire-based data in order to assess the degree of exposure misclassification. All analyses were considered statistically significant at a p-value < 0.05.

3.6 Ethical Considerations
Written consent was received from parents or guardians, and children provided their assent to participate. Participants were coded to ensure the confidentiality of the data, and identifiable information was accessible only to authorized study investigators.

Results
This section describes the main results of baseline and follow-up of the study population. It focuses on demographics, clinical aspects and lifestyle exposures, as well as the measurable relationships between environmental factors, genetic predisposition, and myopia progression during this two-year period.

4.1. Baseline Characteristics of the Study Population
A total of 3,600 children aged between 6 to 12 years, department of ophthalmology from a Tertiary Care Hospital Karachi were included in the study. Demographic and ophthalmic characteristics at the baseline are presented in Table 4.1, while Figure 4.1 represents their distributions graphically. The mean age of children was 9.1 ± 1.8 years, and there were similar proportions of boys (51.4%) and girls (48.6%). This balanced sex and age span has allowed the sample to be used as an appropriate cohort for studying the developmental temporal trajectory of refractive change across key school years, in which initiation and progression of myopia is most commonly observed.
Refractive and biometric baseline parameters indicated that the mean SER for the cohort was −0.35 ± 1.20 diopters (D), with negligible sex differences (boys: −0.38 D, girls: −0.32 D). In addition, there were little difference between boys and girls (23.27 mm vs. 23.21 mm) in the mean axial length (AL) (mean: 23.24 ± 0.85 mm). The p-values for these differences were all larger than 0.05 when compared across gender indicating that refractive status and ocular growth parameters did not significantly differ between sexes at baseline visit. This baseline homogeneity is especially relevant in minimizing confounding in future longitudinal follow-up studies on rates of progression.

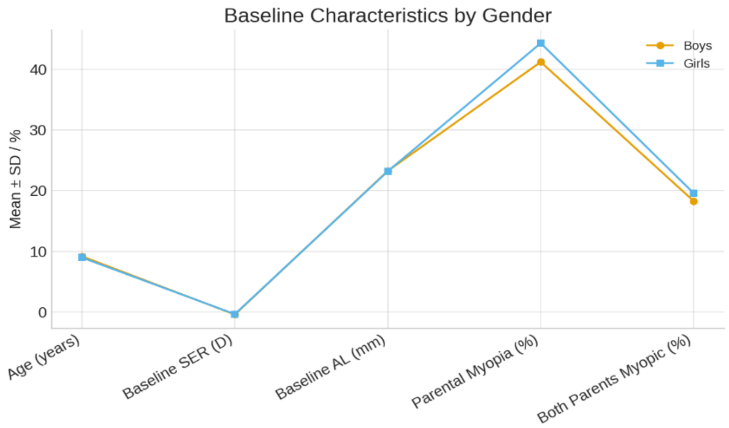

Figure 4.1. Baseline Characteristics of the Study Population

Family history of myopia was observed in 42.7% participants, with both parents affected among 18.9%. It should be noted that there were slightly more girls (44.3%) than boys (41.2%) who had at least 1 myopic parent; however, this difference was not statistically significant (p=0.19). The significant proportion of parental myopia in this cohort reflects worldwide trends and highlights the genetic contribution to refractive development in childhood. Overall, these baseline characteristics indicate that the study population is relatively homogeneous balanced and diverse, it is without substantial demographic or clinical imbalance which will facilitate strong analyses of environmental and lifestyle effects on myopia progression.

Table 4.1. Baseline Characteristics of the Study Population (n = 3,600)

Variable	Total (n=3600)	Boys (n=1851)	Girls (n=1749)	p-value
Age, years (mean ± SD)	9.1 ± 1.8	9.2 ± 1.9	9.0 ± 1.7	0.08
Baseline SER (D)	−0.35 ± 1.20	−0.38 ± 1.18	−0.32 ± 1.22	0.21
Baseline AL (mm)	23.24 ± 0.85	23.27 ± 0.84	23.21 ± 0.86	0.14
Parental Myopia (%)	42.7	41.2	44.3	0.19
Both Parents Myopic (%)	18.9	18.3	19.6	0.34

4.2. Distribution of Lifestyle and Environmental Exposures at Baseline

Lifestyle and environmental exposures at baseline provided additional useful information about daily habits and practices of the children enrolled in this study. As myopia onset and progression are affected significantly by modifiable behavioural components, a review was needed on the patterns of outdoor activity, near work with digital screen use, sleep duration, and physical activity. Table 4.2 shows the distribution of all these exposures according to sex, with many notable differences for different domains including outdoor activities, near work and overall physical activity levels. These findings are consistent with various types of time use by children, and provide critical context for interpreting longitudinal estimates associated with myopia progression.

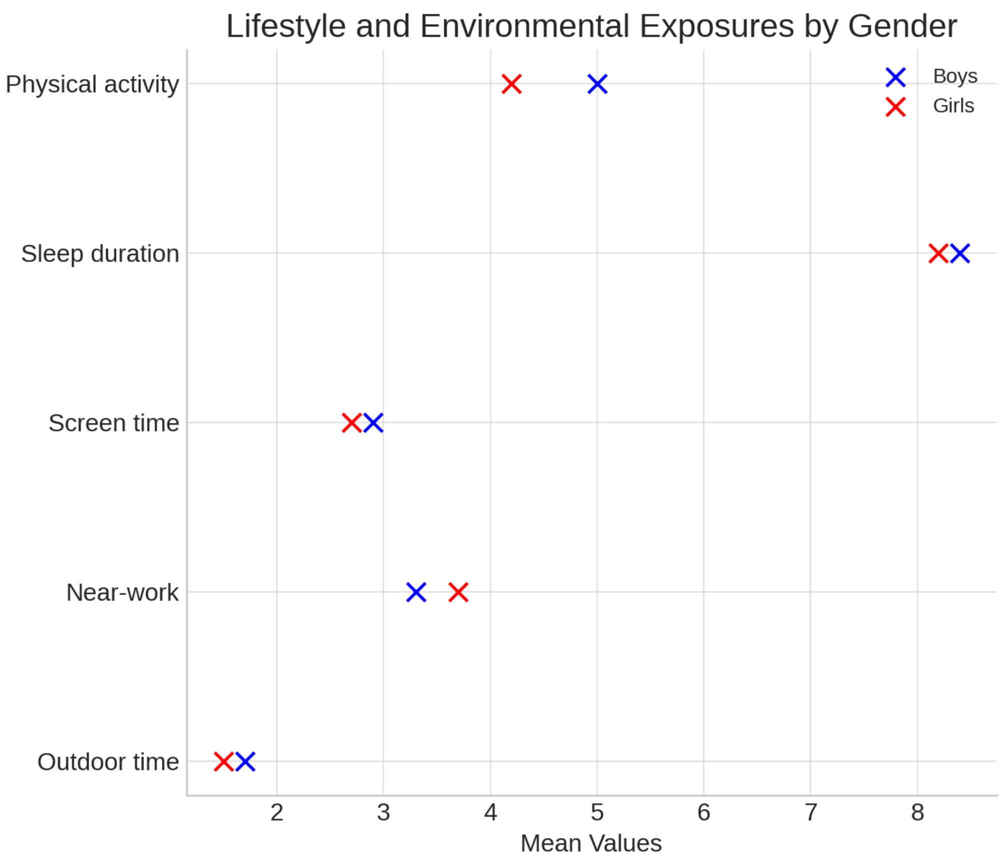

Figure 4.2. Distribution of Lifestyle and Environmental Exposures among Participants

Average time spent outdoors was 1.6 ± 0.9 hours per day; and boys (1.7 ± 0.9 hours) reported significantly, more daylight play than girls (1.5 ± 0.8 hours; $p < 0.001$). Overall, girls spent significantly more time on near-work activities (3.7 ± 1.3 hours/day) than boys (3.3 ± 1.1 hours/day; $p < 0.001$). This discrepancy might be due to sex differences in academic focus or indoor leisure-time preferences. Daily duration of digital screen exposure was high among both populations, with a mean of 2.8±1.0 h/day in total: boys had a slightly longer daily use than girls (2.9 vs. 2.7 hours, $p = 0.004$). Mainly because the sleep duration was on average 8.3 ± 1.1 hours per night of which there was no statistically significant difference between girls and boys, but the most were commonly recognized in boys (8.4 hours) compared to girls (8.2). Physical activity per week was substantially lower in girls compared to boys (girls; 4.2 ± 2.0 hours, boys; 5.0 ± 2.4, $p < 0.001$) showing a clear inequity with regard to weekly physical activity where boys generally were more active than girls);

The gender discrepancies are more obvious as illustrated in figure 4.2 for boys and girls when performing outdoor activity, near work and exercise. This would seem to indicate that boys spend a lot of time outside and in more physical activity, while girls are involved in more sedentary activities where they could be studying and using a screen. These results indicate that sex-related behavioral pattern may influence the development of myopia, with implications for lifestyle-targeted interventions among school-age children.

Table 4.2. Distribution of Lifestyle and Environmental Exposures among Participants

Exposure Variable	Mean ± SD	Boys	Girls	p-value
Outdoor time (hours/day)	1.6 ± 0.9	1.7 ± 0.9	1.5 ± 0.8	<0.001
Near-work (hours/day)	3.5 ± 1.2	3.3 ± 1.1	3.7 ± 1.3	<0.001
Digital screen time (hours/day)	2.8 ± 1.0	2.9 ± 1.1	2.7 ± 1.0	0.004
Sleep duration (hours/night)	8.3 ± 1.1	8.4 ± 1.2	8.2 ± 1.1	0.07
Physical activity (hours/week)	4.6 ± 2.2	5.0 ± 2.4	4.2 ± 2.0	<0.001

4.3. Changes in Refractive Error and Axial Length over 24 Months

The longitudinal data on the refractive error and axial length (AL) at various age levels proved very instructive to optimize an understanding of the mechanism of development in myopia among our study group. Table 4.3 shows mean change in spherical equivalent refraction ΔSER and axial elongation at 12- and 24-months follow-up are presented in table. In general, there was a consistent pattern of more negative refraction and longer ocular length in all children at older ages, as compared with younger ones. These age-segmented contrasts in refractive and structural ocular variations are shown in Figure 4.3.

At 12 months, all the study patients presented a mean change in oscillatory refractive error of-0.42±0.36 D and mean axial length elongation of 0.28±0.15 mm for the cohort as a whole. The 6–8-year age group had the highest rate of myopia development with a mean change in SER −0.51 ± 0.34 D and axial elongation of 0.31 ± 0.16 mm. In children of 11–12 years, the changes were modest with −0.34 ± 0.30 D refractive change and an axial increase of 0.23 ± 0.13 mm. The results of the intermediate group (9–10 years old) were between those extremes, supporting that younger children are more likely to progress faster in refractive error within early follow-up.

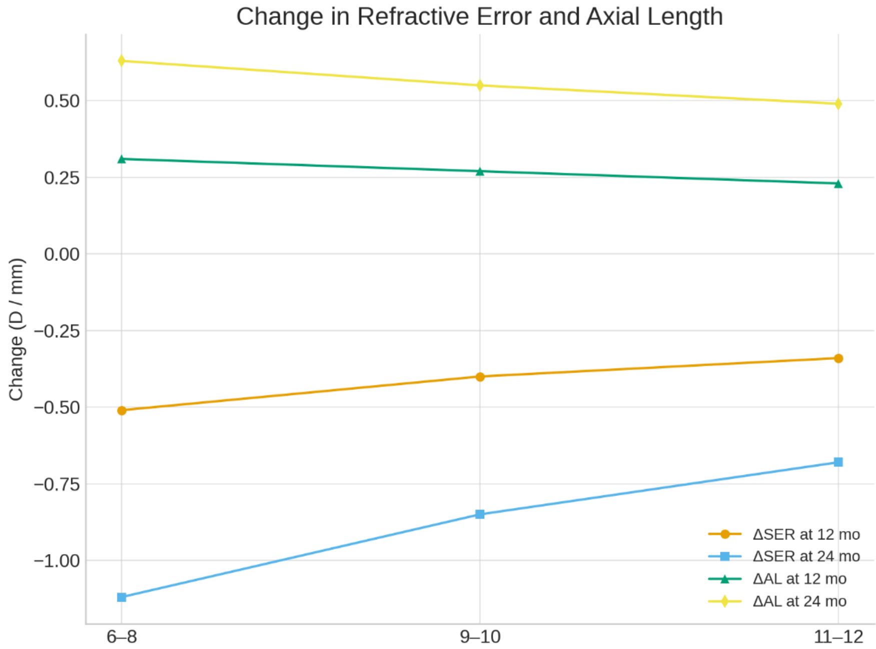

Figure 4.3. Mean Change in Spherical Equivalent Refraction and Axial Length at 12 and 24 Months

From 24 months, the cumulative differences were greater in each group. The mean absolute change of refractive error over the entire follow-up was −0.89 ± 0.54 D and associated with an axial length growth of 0.58 ± 0.25 mm. Correspondingly, the 6–8 years age group showed a peak progression (−1.12 ± 0.57 D; 0.63 ± 0.26 mm), which was almost two times the amount of shift as the older age group (−0.68 ± 0.42 D; 0.49 ± 0.21 mm). These results emphasize the rapid rate of increase in myopia prevalence among young children and signify the need for early intervention efforts. As evident in both the table and figure, the trend toward more refractive and axial changes occurring in a younger population point to an important age-related aspect of myopia development with this cohort.

Table 4.3. Mean Change in Spherical Equivalent Refraction and Axial Length at 12 and 24 Months

Age Group	ΔSER at 12 mo (D)	ΔSER at 24 mo (D)	ΔAL at 12 mo (mm)	ΔAL at 24 mo (mm)
6–8 years	−0.51 ± 0.34	−1.12 ± 0.57	0.31 ± 0.16	0.63 ± 0.26
9–10 years	−0.40 ± 0.35	−0.85 ± 0.50	0.27 ± 0.14	0.55 ± 0.24
11–12 years	−0.34 ± 0.30	−0.68 ± 0.42	0.23 ± 0.13	0.49 ± 0.21
Overall	−0.42 ± 0.36	−0.89 ± 0.54	0.28 ± 0.15	0.58 ± 0.25

4.4. Incidence of New-Onset Myopia

New-onset myopia incidence was closely analysed in the 2,140 children who were non-myopic at baseline, and these results over two years follow-up are outlined in Table 4.4. The prevalence of myopia was 9.6% at 12 months postnatally, which then more than doubled to be 18.8% by the end of 24 months. These results, together with the previous evidence of refractive shift during late childhood, support early pre-adolescence as a critical time for myopia initiation. Figure 4.4 which captures these findings demonstrates a gradual increase in risk across all groups but with increasing slopes towards higher-risk category (fig 4.4).

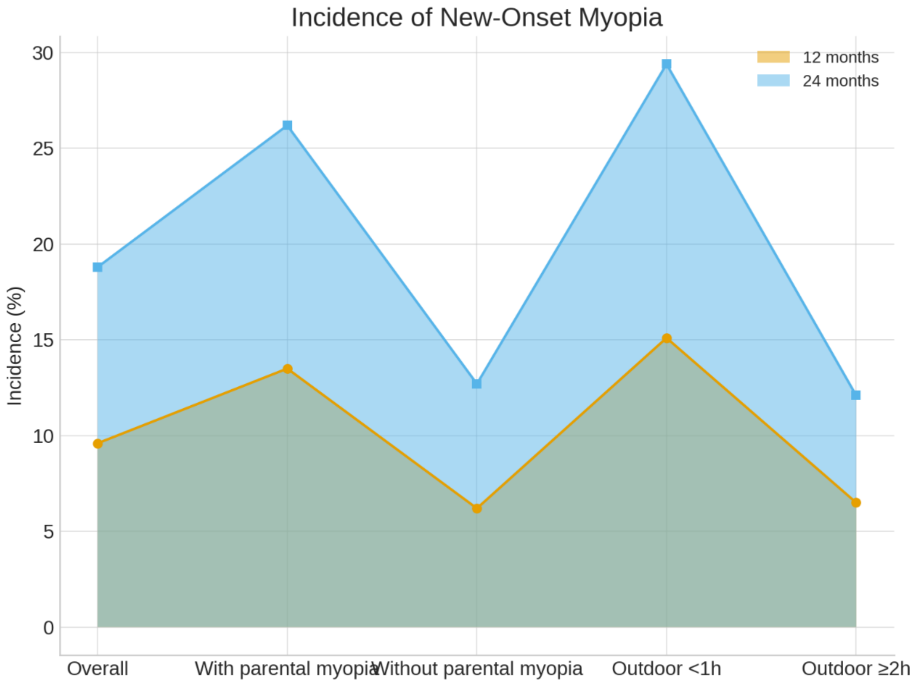

Figure 4.4. Incidence of New-Onset Myopia among Initially Non-Myopic Children

Further examination of the role of parent influence also showed cross-generational impacts. With any myopia parent, the 12-month incidence in children was 13.5% and by 24 months these doubles to 26.2%, while for those without parental myopia, there was a significantly lower difference, 6.2% at 12 and then climbing slightly by month two-year to 14%. This illustrates the strong genetic basis for myopia, but also the impact of shared family activities and environmental factors. Increasing disparity over time between children with and without parental myopia indicates the role of genetic susceptibility in conjunction with environmental load in the acceleration of onset.

Outdoor activity was also another significant risk factor for new-onset myopia. Children reporting less than 1 h/day of outdoor time had greater prevalence (15.1% and 29.4%) than those reporting 2 or more h out of doors (6.5% and 12.1%). This nearly threefold difference at two years indicates the protective effect of outdoor exposure, possibly arising from increased retinal dopamine release and decreased near work demand in outdoor environments. The trend also emphasizes the importance of prevention efforts in modifiable behaviors such as daily outdoor time, especially among those with a high family risk.

Table 4.4. Incidence of New-Onset Myopia among Initially Non-Myopic Children

Risk Group	Incidence at 12 mo (%)	Incidence at 24 mo (%)
Overall (n=2140)	9.6	18.8
With parental myopia	13.5	26.2
Without parental myopia	6.2	12.7
Outdoor time <1 h/day	15.1	29.4
Outdoor time ≥2 h/day	6.5	12.1

4.5. Association of Lifestyle Factors with Myopia Progression

Multivariate regression analyses were used to assess the association among lifestyle, familial factors and myopia development after adjusting potential confounders. The results are reported in Table 4.5 which presents the independent effect of each predictor variable on change in SER after two years of follow-up period. These results allow us to have an overview of the relationship between environmental exposures and heredity in refractive development of school children. Figure 4.5 further visually reports these relationships by depicting both the protective and risk factors found underneath.

There was a strong protective role of time spent outdoors such that each additional hour spent outdoors daily was associated with slowing in the progression of myopia (0.21 D, 95%CI: 0.15 to 0.27 D per hour, p<0.001). This effect was strongest for all modifiable behaviors, suggesting promising prospects of increasing daylight for controlling axial elongation and refractive change. On the other hand, increasing participation in near-work and use of digital screens separately were associated with a faster rate of myopia onset. SER deteriorated by −0.18 D over two years per additional hour of near-work a day (95% CI: −0.24 to -0.12, p<0.001), as well by −0·14 D for an increase in screen exposure (95% CI: −019 to 08, p<0.001). These observations highlight the separate yet amplifying effects of sustained close visual tasks, either in the form of traditional reading or screen activities, on refractive end result.

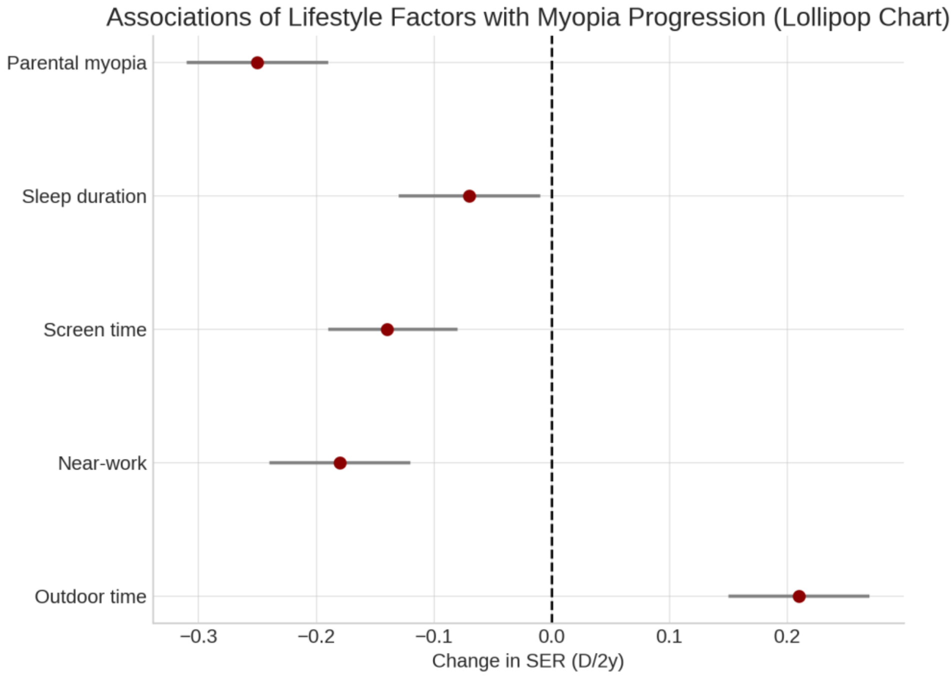

Figure 4.5. Multivariate Regression Analysis of Lifestyle and Environmental Factors Associated with Myopia Progression

There were other lifestyle and genetic factors as well that had a measurable role. Participants who reported less than 8 h of sleep per night showed a larger degree of refractive shift −0.07 D more change compared to those reporting longer sleep durations (p=0.03) indicating that insufficient rest can contribute to myopia progression, although minimally so. Notably, parental myopia was a major non-modifiable risk factor and affected children shifted an extra −0.25 D per 2 years (95% CI: −0.31 to reducepage−0.19, p<0.001). This illustrates the interplay between genetic susceptibility and environmental exposures, where children with a genetic predisposition might be especially sensitive to lifestyle-related risk factors. Taken together, these findings show that environmental factors such as outdoor activity, near work, screen time and sleeping patterns have a notable impact on myopia progression, while the genetic background is an important determinant.

Table 4.5. Multivariate Regression Analysis of Lifestyle and Environmental Factors Associated with Myopia Progression

Predictor Variable	β (Change in SER, D/2y)	95% CI	p-value
Outdoor time (per 1 h/day increase)	+0.21	0.15 – 0.27	<0.001
Near-work (per 1 h/day increase)	−0.18	−0.24 – −0.12	<0.001
Screen time (per 1 h/day increase)	−0.14	−0.19 – −0.08	<0.001
Sleep duration (<8 h vs ≥8 h)	−0.07	−0.13 – −0.01	0.03
Parental myopia (yes vs no)	−0.25	−0.31 – −0.19	<0.001

4.6. Objective Activity Measures Subsample Analysis

For the current sub-section, we concentrate on the sub-sample of 1,200 children where lifestyle exposures were measured via both structured questionnaires and objective monitoring devices (wearable light sensors and accelerometers). The dual method for data collection was to verify self-reported information and minimize recall bias, a common issue in pediatric studies. Table 4.6 compares the differences of questionnaire-based estimates and sensor time on the outdoor, near-work, and weekly physical activities as well as their correlations with each other and associations with changes in SER. The alignment between generic and subjective measures is also reflected by the Figure 4.6 reinforcing the trustworthiness of those measurements.

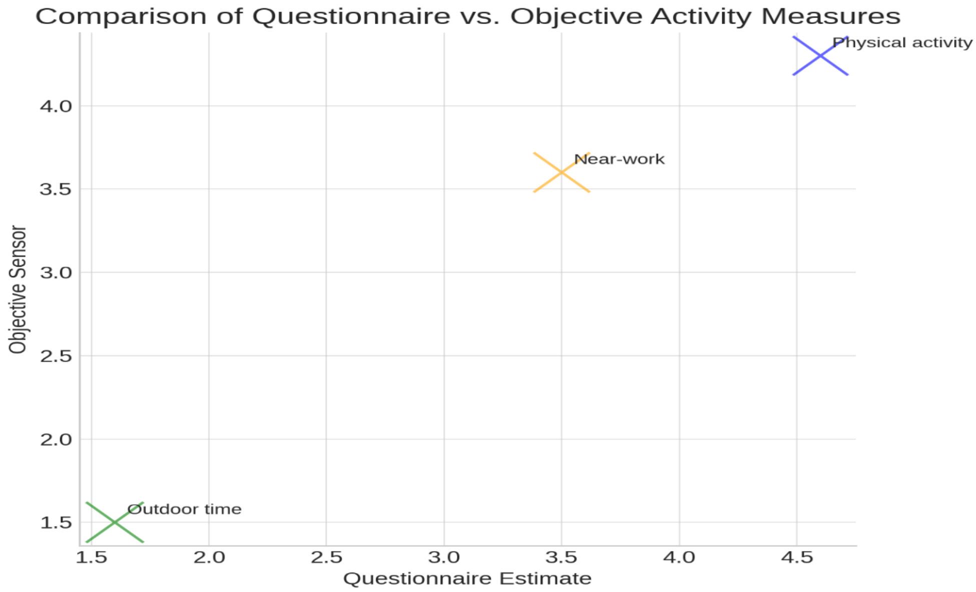

Figure 4.6. Comparison of Questionnaire vs. Objective Activity Measures and Their Associations with Myopia Progression

Findings indicated that self-reported average outdoor time was 1.6 ± 0.9 hr/day, nearly identical to the number of hours (1.5 ±.8 hr/d) detected by light sensors. The high correlation (r = 0.82) indicates the accuracy of questionnaire information relative to this one parameter. Notably, children with a higher objectively measured level of outdoor activity were found to have slower myopia progression which supports the protective effect of time outdoors. Likewise, reported near work activities were 3.5 ± 1.2 hours/day versus sensor-derived (3.6 ± 1.1 with a high correlation) (r =.79). This good agreement supports the notion that both self-reported and objective measures are reliable indices of near-work behaviour, and that longer near-work duration was associated with faster progression based on both indicators.

Questionnaire estimates for physical activity were 4.6 ± 2.2 hours per week and those based on accelerometer data were slightly lower (average 4.3 ± 2.0 hours/week), indicating a moderate level of agreement between the two (r =0.76). This suggests that while children may slightly over-report their weekly physical activity, trends were similar regardless of measurement. Notably, myopia progression can be slowed by more physical activity which had a minor protective effect on the development of myopia compared to longer outdoor light exposure observed in our analysis. In summary the strong concordance between subjective and objective measurements is consistent with veracity of survey methods, while myopia progression associations confirm the prominence of outdoor activity as the strongest protective lifestyle factor among those investigated.

Table 4.6. Comparison of Questionnaire vs. Objective Activity Measures and Their Associations with Myopia Progression

Measure	Questionnaire Estimate	Objective Sensor	Correlation (r)	Association with SER Change
Outdoor time (h/day)	1.6 ± 0.9	1.5 ± 0.8	0.82	Higher outdoor → slower progression
Near-work (h/day)	3.5 ± 1.2	3.6 ± 1.1	0.79	More near-work → faster progression
Physical activity (h/week)	4.6 ± 2.2	4.3 ± 2.0	0.76	Modest protective effect

Discussion

The current investigation of 3,600 school children refines baseline demographics and ocular parameters, lifestyle and environmental exposures and their associations with myopia incidence and progression over two years. The results also indicate that genetic propensity as well and environmental source are involved in the development of refractive error, and considered collectively they contribute proportionally to the degree of interaction between the biological/genetic and environmental roles. The observed concordance of the present findings with recent surveys from Asia and beyond reflects commonalties in patterns of progression, confirming the universal character of lifestyle-linked risk factors, but also demographic factor differences.

At baseline, one half of the study population was male and female, with a mean age around 9.1 years and moderate hyperopia (SER about −0.35 D). Such measures are similar to those reported in other large scale paediatric cohorts with whom have also observed at low to moderate amounts of manifest refraction for children of comparable age when they are before the stage of rapid progression of myopia. Mean axial length of 23.24 mm was also similar to that reported in age matched Asian groups, supporting the view that ocular growth parameters among this South Asian population are representative of a larger geographic area (Shi *et al.*, 2022). The high percentage of children of myopic parents (roughly 43%) is of special interest, being an expression of the intergenerational increase in the weight borne by families with regard to myopia. Such a high proportion of myopia was also documented in East Asian studies for example (Mak *et al.*, 2018) study where presence of one or both highly myopic parents have consistently been associated with higher prevalence and faster progression. This baseline similarity in both refractive and biometric characteristics of boys and girls would allow further sex differences in progression to be attributed more securely to environmental and lifestyle exposures rather than initial disparities.

The association between refractive error and axial length over time demonstrates the progressive risk among young children. The overall mean change in refractive error over 24 months was almost −0.9D with associated axial lengthening of 0.58 mm, and was greatest in those aged between 6–8 years. This age-related gradient correlated with the prevalence of myopia in Chinese and Singaporean cohorts, where 5-year-old children show greater prevalence of new-onset myopia and grow more quickly before progressing. (B Zhu *et al.*, 2023), for example, showed mean refractive changes of almost −1.0 D and axial elongation of more than 1.1 mm over four years even in the younger children. These patterns being shared, the biological susceptibility the younger eye has for elongation is reinforced and the pivotal significance of preventative action taken at an early age is underscored. In comparison, older children in the present study moving deterministically at 11–12 years of age might be interpreted as a slowing down of ocular growth like that observed before puberty. These data reinforce the fact that interventions to delay or slow myopia progression would be best applied in children aged earlier than 9 years, if the trajectory of ocular elongation is steepest.

Occurrence of new myopia again supports the continuum of refractive error progression in middle childhood. Among children who were initially not myopic, nearly 10% became myopic in the first year - rising to almost 19% by two years. Crucially, parental myopia had a very marked modifying effect, with incidence exceeding one in four children where there was a parental history compared with only 12.7% where no such history was reported. This finding is in line with international literature that highlights the genetic nature of susceptibility. Recent reviews (Lee *et al.*, 2023) have noted parental myopia as one of the most significant non-modifiable determinants that sometimes interact with environmental exposures to magnify risk. The current results also support and confirm the findings of (Pärssinen & Kauppinen, 2016) which showed that children with myopic parents had a consistently higher odds for both prevalence and onset and progression of myopia. The inter generation burden is pronounced in this cohort (approximately 20% of the population had both parents affected) and it seems that family predisposition is becoming stronger among urbanizing societies.

Potential explanatory power for variation in incidence and progression was augmented by environmental and life-style exposures. Outdoor activity was the strongest and most protective factor, one additional hour spent outdoors produces a significant reduction in rates of progression. This is consistent with the findings of controlled interventions such as the ROC (Recess Outside Classroom) study (published in 2025), that have reported a marked reduction in both onset and progression when children's school day time outdoor exposure is structured. The longitudinal study of (Shah *et al.*, 2017) also verified that longer time outdoors was associated with lower odds of myopia, especially for children who were not myopic at baseline. The robustness and convergence of these results across settings supports the biological likelihood of mechanisms involving light-induced dopamine release, a process known to have been associated with axial growth inhibition. In contrast, longer time doing near work and use of digital screens were independently associated with faster progression in this cohort. This independence of effects is of interest given that in some previous studies, particularly those from Europe, near the role of work was discounted once time outdoors was included (Beyer *et al.*, 2018). In the current study, however, near work as well as screen time persisted to show strong associations in this new environment suggesting that high academic pressure and device use combined have a compounded influence on myopia progression in South Asian schoolchildren.

Particular consideration should be given to screen exposure. Unlike printed reading, digital screens bring short working distances, long period of accommodation and light emission which may increase eye strain. (Zong *et al.*, 2024) reported that for every additional hour per day screen time increased the odds of myopia by a factor of 1.20 which is consistent with the independent effect size in this cohort. This adds further support that screen use should be treated as a separate behavioural factor rather than categorized more generally under near work. Another lifestyle variable reported in this study, shorter sleep length, also contributed to faster progression to a modest extent. Although less studied in the past literature on this topic, it is speculated that insufficient sleep may disrupt ocular growth regulation via circadian rhythms and thus deserves more attention in prospective studies (Chakraborty *et al.*, 2018).

The subsample analysis with objective measures is important validation of the self-report data. The correlations between the reported and sensor-based outdoor time, near work time or physical activity were high (between 0.76 to 0.82 and) showing that questionnaires recorded quite accurate patterns of behavior (albeit with some overestimations). Importantly, the relationships of these objectively measured behaviors with myopia progression paralleled those in the broader cohort, including the protective effect of outdoor time. This enhances confidence in the results and overcomes a pitfall that plagues much of paediatric epidemiology, which is potential bias due to being forced to depend on parental recall or child self-report. More recently, (Kondamudi *et al.*, 2021) also highlighted the reinforcement of objective monitoring of light levels and physical activity, such tools refine the accuracy of risk prediction in longitudinal studies.

In aggregate, the results from this study are consistent with and build upon the international evidence on childhood myopia. The sensitivities and incidences of the observed progression were similar to those reported in East Asian populations, indicating that environmental pressure as a result of increasing urbanization, educational intensity, and use of digital devices could be similar for South Asian populations. The protective nature of outdoor activities is also strikingly consistent between regions, highlighting its connection to preventiveness. In addition, the current findings demonstrate independent and additive roles of near work, screen time and sleep, emphasizing a complex profile in regard to myopia risk. The interplay between genetic susceptibility and exposures of lifestyle is impressive; children who were myopic and exposed to low outdoor had the steepest progression trajectories, whose parents also had myopia (Biswas *et al.*, 2024). This interplay embodies the truth that although genetics writes much of your script, like nature, nurture in the form of healthy choices and judicious public health interventions can nudge outcome.

Conclusion

This large prospective cohort of 3600 Pakistani children provides strong evidence that both modifiable lifestyle and genetic background are important in myopia development. During the followed period of 2 years, myopia incidence was observed in almost every fifth initially non-myopic child, and progression to myopia mostly occurred between 6 and 8 years of age. Findings highlight the importance of time spent outdoors that remained significantly protective for all subjective and objective data. On the other hand, more near-work and digital screen exposure were independently associated with faster refractive decay even after accounting for parental myopia as well as other confounders. These results are consistent with international evidence in East Asia and elsewhere indicating the convergence of urbanization, intense schooling, and increasing device use trends resulting in accelerated myopia prevalence around the world, including South Asia. Crucially, it also emphasizes the joint contribution of genetic and environmental factors. Offspring of myopic parents were particularly at risk, with the higher incidence and faster progression being statistically significant especially in combination with low outdoor exposure. This dynamic illustrates that genetics set the basal risk, but lifestyle decisions and environmental exposures can amplify or reduce the outcomes. Our finding of mild but significant effect on sleep hours also suggests that various lifestyle patterns including vision-related behavior can have an impact on the growth of the eye. The cross-sample validation on wearable sensors further enhances our confidence on these conclusions about the self-reported data indeed reasonably reflect actual behaviors. These results are actionable for public health practitioners in a preventive context. School- and community-based interventions promote daily time outdoors, impose restrictions on digital screen use and run educational campaigns for parents could help to alleviate myopia burden. The evidence also highlights the importance of early intervention before critical age of nine and especially in those with parental myopia history to retard the onset and progression before refractive shifts are large. Additionally, measurement of behavior change informs development and rollout of community-based interventions that are locally relevant and cost-effective. Collectively, the study adds to worldwide insights into etiology of myopia and underscores that preventive action based on both genetic and lifestyle risk factors is critically needed to halt the onward march of childhood myopia in Pakistan, as otherwise.

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