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· Review Article ·

Childhood myopia in the modern environment: modifiable risk factors and evidence-based prevention

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Abstract
● This review aimed to summarize modifiable environmental and lifestyle risk factors for childhood myopia and evaluate evidence-based preventive strategies for family, school, and public health practice. Following the PRISMA-ScR framework, relevant studies on children aged 5–18y published up to January 2026 were retrieved from mainstream databases, and eligible literature was synthesized according to study design and evidence level. Reduced outdoor activity, excessive near-work and screen exposure, urban residence, insufficient sleep, and gene-environment interaction are major risk factors for childhood myopia. Daily outdoor activity of 1–2h or longer confers protective effects *via* promoting retinal dopamine release and inhibiting axial elongation, whereas prolonged close work and excessive screen time notably elevate myopia risk. Optimizing outdoor time, regulating ocular use habits, ensuring sufficient sleep, and implementing school-based interventions are core evidence-based preventive measures, and wearable devices and objective biomarkers can facilitate behavioral management and intervention evaluation. In conclusion, childhood myopia is influenced by multiple adjustable factors; increased outdoor exposure is the most effective preventive measure, and combined behavioral and policy interventions are essential to curb the global prevalence of childhood myopia and prevent subsequent severe visual complications.
● **KEYWORDS:** myopia; incidence; academic activities; risk factors; near-work; school-aged children; outdoor activities
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INTRODUCTION
Myopia has emerged as one of the most important public health issues of the 21st century and its prevalence is rapidly increasing amongst school-going children in the world. Recent global projections estimate that by 2050, nearly 50% of the world's population will be myopic, with high myopia (≤6.00 D) affecting up to 10%[1], and childhood myopia prevalence reaching 35%–47% in East Asia and urban settings[1-2]. In East and Southeast Asia, rates among young adults frequently exceed 80%–90%, and high myopia in adolescents is projected to rise significantly (*e.g.*, 17%–22% in China by 2050)[3-5]. In addition to refractive error, myopia is a significant contributor of sight threatening complication such as myopic macular degeneration, retinal detachment, glaucoma, and cataract, which is adding to an escalating visual impairment and blindness burden[6-8]. The economic impact is profound, with direct costs for correction and management running into billions annually and global productivity losses from uncorrected myopia and complications exceeding \$200–\$250 billion[9]. These escalating figures highlight the urgent need for effective, evidence-based prevention targeting modifiable risk factors.

Although genetic factors contribute significantly, the explosive rise in myopia prevalence far exceeding genetic shifts underscores the dominant role of environmental and lifestyle influences[10]. Myopia rates show significant geographical variation, with East and Southeast Asian populations experiencing notably higher prevalence at 47%, more than double the rates seen in other regions[11]. Countries such as China, Japan, South Korea, Singapore, Taiwan Province of China, and Hong Kong Special Administrative Region of China (Hong Kong, China) exhibit notably high prevalence rates in urban areas[1,3-4], while significantly lower figures are reported in Central Africa (7%), Central Europe (27%), and Central Asia (17%)[12]. Urbanization, intensive academic demands, prolonged near-work, limited outdoor time, and excessive screen exposure are consistently implicated, with synergistic interactions amplifying risk[13-14].

Previous reviews have addressed specific myopia risk factors and interventions, including the International Myopia Institute (IMI) 2025 updates on controlling onset and progression[2,4], systematic syntheses of environmental and lifestyle[15-16] and focused analyses of childhood myopia trends[14,17]. A recent review examined the mechanisms by which outdoor exposure prevents myopia onset and progression, focusing specifically on dopamine pathways, light intensity, and spectral composition[18]. However, such reviews are narrow in scope, focusing on isolated factors and lacking full integration of the complete network of modifiable risk factors, including near-work, screen time, urbanization, sleep, diet, and gene-environment interactions, as well as recent post-pandemic evidence, synergistic interactions, and emerging technological interventions such as wearable devices and low-level red-light therapy. The present review uniquely addresses these gaps by providing a holistic, actionable prevention framework integrating all major modifiable determinants of childhood myopia, specifically tailored to school-aged children across school, family, and public health levels.

Methods Used to Conduct the Review This broad narrative review aimed to summarize evidence relating to the modifiable environmental and lifestyle determinants of myopia in school aged children including a focus on the evaluation of preventive interventions. To enhance transparency and rigor, we adapted elements of the PRISMA extension for Scoping Reviews (PRISMA-ScR) guidelines[19], which emphasize structured reporting for exploratory syntheses. The protocol was not pre-registered as this is a narrative review and not a full systematic review; however, we were able to follow a predefined search and selection process to minimize bias.

MEDLINE, PubMed, EMBASE, Web of Science, and Scopus were searched on English language studies published from inception to January 2026. The search strategy was a combination of keywords and Medical Subject Headings (MeSH) headings related to refractive errors, environmental exposures, lifestyle behaviors, and pediatric demographics, namely: "Myopia", "Childhood Myopia", "Environmental Factors", "Lifestyle Factors", "Near-Work", "Screen Time", "Outdoor Time", "Light Exposure", "Refractive Error", "School-aged Children", "Pediatric Myopia", "Urbanization", "Education", "Physical Activity", as well as synonyms: "short-sightedness", and "nearsightedness". Boolean operators (AND/OR) were applied. No date restrictions were imposed. Full-text review was performed and reference lists of included studies and recently published reviews (*e.g.* IMI 2025 update)[4] were hand-searched for further publications.

Eligibility criteria focused on studies conducted in school-aged children (5–18 years old) that examined modifiable environmental or lifestyle factors and preventive interventions for myopia. Two independent reviewers screened for studies in terms of title and abstract, followed by full text evaluation. Disagreements were resolved *via* discussion with a third reviewer. We extracted data on study design, population, exposures, outcomes, and findings using a standardized form. As this study is a narrative review based entirely on previously published literature and did not involve direct recruitment of human participants, ethics committee approval was not required.

To overcome possible bias, the quality of studies was critically appraised, giving high quality evidence to randomized controlled trial and longitudinal cohort study evidence and lower level of evidence to cross section study (hierarchy based on the Oxford Centre for Evidence-Based Medicine). Synthesis was thematic and narrative, integrating synergistic effects and geographical variations, without meta-analysis due to heterogeneity. A PRISMA-ScR flow diagram (Figure 1) represents the selection process. This framework delivered an overall picture with integrated systematic elements to promote reproducibility.

Literature Review The etiology and progression of myopia in school-aged children are controlled by complex gene and environmental interactions, where modifiable factors in the environment and lifestyle are predominant in the recent uptick at the global level[2,4]. Table 1 summarizes the key risk factors, graded by evidence quality [high: randomized controlled trials (RCTs)/longitudinal cohorts; moderate: well-conducted cross-sectional/Meta-analyses; low: ecological or small observational studies].

Myopia and Environmental Influences The leading environmental factors that statistically influence childhood myopia are geographical variations, urbanization, as well as educational demands and near-work activities. These factors interact synergistically and are modifiable, offering key opportunities for prevention[2,4].

Geographical variations and urbanization Myopia prevalence shows marked geographical variation, with the highest rates in urbanized East and Southeast Asian regions[1,3]. Recent global meta-analyses estimate childhood myopia

Table 1 Key modifiable risk factors for childhood myopia: evidence, mechanisms, and interventions

Risk factor	Evidence strength & key references	Proposed mechanism	Recommended interventions
Reduced outdoor activity	Strong (RCTs, cohorts, Meta-analyses)[2,14,53,58]	Bright light (>1000–3000 lx) stimulates retinal dopamine, inhibiting axial elongation[57,63]	≥1–2h/day outdoor time in schools; structured recess; green space access; CUVAF monitoring[54-56]
Prolonged near-work	Strong (Meta-analyses, longitudinal studies)[41-42]	Accommodative lag–peripheral hyperopic defocus–axial elongation[46-47]	20-20-20 rule; viewing distance ≥30–40 cm; limit continuous near-work >30–45min[65]
Screen time & digital devices	Moderate (observational, post-COVID cohorts)[14,66]	Close distance, reduced blinking, blue light melatonin delay; displaces outdoor time[94]	Limit recreational use (<2h/d); 20-20-20 breaks; blue-light filters; wearable tracking[75]
Urbanization	Strong (urban-rural, NDVI/green space studies)[10,13,63]	Limited green space, high academic pressure, artificial light, reduced outdoor access[16]	Urban green space planning; school outdoor policies; improved lighting standards[56]
Sleep deprivation	Emerging/moderate (Meta-analyses, cohorts)[89-91]	Circadian disruption & melatonin dysregulation affect scleral remodeling[57,93]	9–11h sleep/night; reduce evening screens; consistent sleep schedules; school education[75]
Diet & nutrition/ obesity	Mixed/weak (inconsistent observational data)[80,82-83]	Insulin resistance (obesity); possible roles for vitamin D, A, omega-3 in inflammation & remodeling[85,87]	Balanced diet promotion; obesity prevention; micronutrient monitoring; await RCTs[14]
Parental myopia (GxE)	Strong (consistent, dose-dependent, independent of SNPs)[4,99-100,106]	Genetic predisposition+lifestyle amplification (education, near-work, less outdoors)[107]	Early screening & monitoring; target outdoor time & near-work balance; family education[2]

RCT: Randomized controlled trial; NDVI: Normalized Difference Vegetation Index; CUVAF: Conjunctival ultraviolet autofluorescence; GxE: Gene-environment interaction; SNP: Single-nucleotide polymorphism.

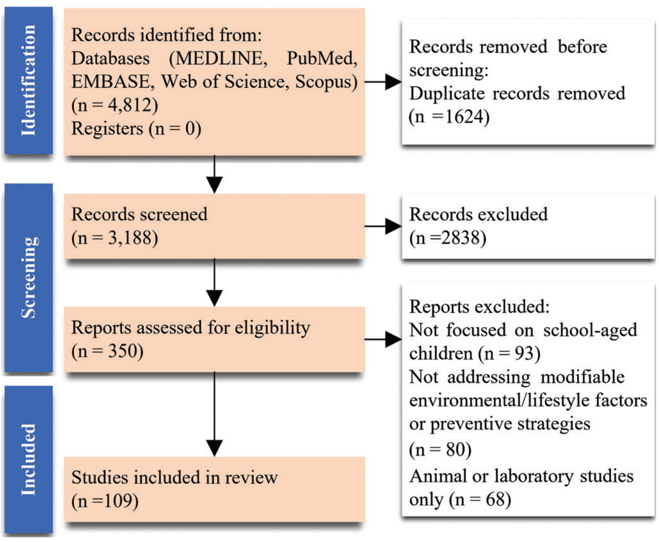

Figure 1 PRISMA flow Chart of literature search.

prevalence at 35%–47% in East Asia, with urban young adults frequently exceeding 80%–90% in China, Republic of Korea, Singapore, Taiwan Province of China, and Hong Kong Special Administrative Region of China (Hong Kong, China)[1,3,14]. In contrast, rates remain substantially lower in rural Africa (4%–7%), Central Asia (17%), and parts of Europe (17%–27%)[12].

Researchers have sought to determine the prevalence of myopia in locations with limited winter daylight to determine the effect of extreme latitudes on visual development[20]. A comprehensive study of Norwegian adolescents[20] revealed a 16% myopia rate under cycloplegic conditions, closely paralleling findings in Northern Ireland (18.6%)[21] and Australia (17.7%)[22]. In contrast, myopia prevalence across European countries varies considerably, ranging from 11.9% in Finland to 49.7% in Sweden under non-cycloplegic conditions, underscoring the substantial geographical variation in refractive error occurrence across the continent[12]. However researchers have yet to reach a unanimous conclusion about whether location itself is significantly associated with myopia[23-29].

Research indicates that living in urban areas may substantially increase the risk of developing myopia. While several studies[30-31], have broadly explored urban-rural disparities, Zhang *et al*[27] showed that higher population density within administrative regions is linked with an elevated risk of myopia in school-aged children of China, regardless of factors like academic pressure, time spent outdoors, parental education levels, and socioeconomic status. Similarly, projections from research in Africa indicate a growing prevalence of childhood myopia in urban environments[32]. Countries experiencing rapid urbanization, such as China, Singapore, and Republic of Korea, report myopia rates ranging from 69% to 73%[33]. Additionally, factors like housing type, size, and floor level have been shown to influence myopia development[34]. Studies indicate that myopia is more common among children living in apartments rather than standalone houses, on higher floors compared to lower floors, and in larger residential spaces[35]. However, these housing-related factors may be intertwined with socioeconomic variables such as education level, income, and occupation[36]. For instance, residing in high-rise apartments may reduce outdoor time and increase near-work activities, further contributing to myopia risk.

Urban expansion is associated with major environmental changes, such as the increase of population densities, the expansion of housing and infrastructural facilities, the diminishing of green areas and social pressures[37]. In addition, substandard infrastructure particularly inadequate indoor and classroom lighting, may amplify myopia risk by reducing exposure to sufficient light intensity[13]. Empirical analysis on the prevalence of myopia in Tianjin[13] found a strong trend: in urbanized localities there were more cases of visual impairment compared to less developed areas. The study demonstrated that students in densely populated urban centers experienced elevated myopia prevalence (67.2%) relative to their peers in less urbanized communities (64.2%). Moreover, a study indicates that a 1-unit increase in urban green space, as measured by the Normalized Difference Vegetation Index (NDVI), is associated with a 3.6% reduction in myopia prevalence[38]. The availability of green areas on school grounds has been linked to a reduced prevalence of myopia at the institutional level and may serve as a protective factor against its development at the individual level[38]. Increasing effective green space is an effective strategy for myopia prevention and holds significant implications for public health and urban planning policies. Higher NDVI values are negatively correlated with myopia progression[39]. A study demonstrated that a 0.1-unit increase in NDVI within buffer zones around schools is associated with a 6.3%–8.7% reduction in myopia prevalence. Additionally, enhancing residential greenness within a 100-meter buffer zone around houses reduces the risk of myopia in preschool children by approximately 38%[40]. Notably, while myopia prevalence is higher in urban areas, severity of myopia may be greater in less developed regions, possibly due to delayed diagnosis and limited access to corrective care[13].

Educational demands and near-work activities Educational demands and prolonged near-work activities remain among the most extensively studied and consistently implicated modifiable risk factors for the onset and progression of myopia in school-aged children, with high-quality Meta-analyses and longitudinal studies demonstrating a modest but significant dose-dependent association between increased near-work exposure and higher myopia risk, particularly in populations with intensive academic systems such as those prevalent in East Asia[14,41]. Societal emphasis on early education, academic achievement, and competitive schooling has led to longer daily hours dedicated to near-work tasks including reading, writing, digital device use, and close-up studying which collectively contribute to the elevated myopia prevalence observed in this demographic, with children in high-pressure educational environments often spending 4–8h per day on such activities[2,41-42].

Quantitative evidence from systematic reviews and Meta-analyses indicates that continuous near-work at distances closer than 30 cm for durations exceeding 30–45min significantly elevates risk, with odds ratios ranging from 1.5 to 2.5 for myopia onset in children aged 12–13y, while each additional diopter-hour of near-work per week increases the likelihood of developing myopia by approximately 1%–2% in dose-response models, though effect sizes vary across populations and are often attenuated after adjustment for outdoor time[43-44]. Supporting this dose-response relationship, a longitudinal study comparing ultra-Orthodox, religious, and secular schoolboys found that the ultra-Orthodox group demonstrated significantly greater myopic shift and axial elongation over 12mo despite similar time outdoors, with risk factors including the ultra-Orthodox educational system and parental myopia, but not screen use, independently predicting faster progression, underscoring the influence of educational intensity and near-work exposure on refractive development[45]. Mechanistically, perseverance in near-work leads to accommodative lag, in which the ocular system does not fully converge on near-work thus inducing peripheral hyperopic defocus which has been shown to be associated with the stimulation of axial elongation[46-47]. Certain longitudinal investigations suggest that accommodative lag precedes the development of myopia and plays a role in early myopia progression, while other studies suggest that it has a greater influence upon progression than initiation. The discordance between findings is likely to be a result of variability of measurement techniques and the presence of confounding factors[48-49]. Prolonged ciliary muscle contraction during near-work may also result in an increase of intraocular pressure and impose mechanical stress in the sclera, although these processes have been hypothesized and need further validation[50]. Early theories linking accommodation directly to myopia were supported by the myopia-inhibiting effects of atropine, which relaxes ciliary muscle tone, but contemporary research attributes atropine's efficacy primarily to non-muscarinic pathways, thereby questioning accommodation's central causal role and shifting focus toward other mechanisms such as peripheral defocus and retinal signaling[51].

Evidence quality for the near-work association is moderate: most data derive from observational studies relying on self-reported or questionnaire-based exposure measures, which are subject to recall bias and confounding by outdoor time, urbanization, educational pressure, and socioeconomic status[14,41]. Randomized trials isolating near-work reduction are scarce, and effects are frequently attenuated or non-significant after controlling protective factors such as outdoor exposure, suggesting that near-work alone is unlikely to fully account for the myopia epidemic but likely acts synergistically with other environmental influences. Despite these limitations, reducing continuous close work, enforcing regular breaks (*e.g.*, 20-20-20 rule), and optimizing viewing distances remain practical, low-cost components of school-based myopia prevention strategies, particularly when combined with increased outdoor time and policy-level educational reforms[2,14,52].

Lifestyle Factors and Myopia In addition to environmental factors, modern lifestyles are also closely related to myopia progression.

Reduced outdoor activities and sunlight exposure Reduced outdoor activities and sunlight exposure represent one of the most robust and consistently supported modifiable risk factors for myopia onset and progression in school-aged children, with high-quality evidence derived from randomized controlled trials, longitudinal cohort studies, and Meta-analyses demonstrating that spending at least 1–2h per day outdoors significantly lowers myopia incidence in a dose-dependent manner, often achieving reductions of 20%–50% in new cases, particularly when light intensity exceeds 1000–3000 lx as encountered in natural daylight[2,14,53]. School-based interventions that mandate additional outdoor recess or structured outdoor time have proven highly effective in real-world settings, with large-scale programs in Taiwan Province of China, Singapore, and mainland China showing substantial decreases in both the incidence of new myopia cases and the rate of progression among already affected children, highlighting the feasibility and public health impact of policy-driven outdoor promotion[54-56].

The primary protective mechanism is widely attributed to bright natural light stimulating retinal dopamine release, which functions as a key "stop" signal inhibiting axial elongation and scleral remodeling, a pathway strongly supported by animal models where light-induced dopamine upregulation prevents form-deprivation myopia and by human studies linking higher cumulative ambient light exposure to slower myopic shifts independent of physical activity levels[57-58]. Additional proposed mechanisms include the synthesis of vitamin D from UVB exposure in sunlight, although observational associations with axial length and myopia risk remain inconsistent and frequently confounded by socioeconomic status, education, and other lifestyle variables[59]. Bright outdoor light also induces pupillary constriction, which increases depth of focus and enhances retinal image quality, while the distant viewing typical of outdoor environments promotes relaxed accommodation and reduces near-work strain on the ciliary muscles, further alleviating accommodative stress and fatigue[60-61].

Animal research exploring the role of light spectrum has revealed wavelength-specific effects, with narrowband long-wavelength red light inducing myopic shifts in certain species, whereas shorter wavelengths such as blue and violet predominant in natural daylight exhibit protective effects against experimental myopia; however, these findings are species-dependent and not yet fully translatable to humans, suggesting that the broad spectral composition of natural sunlight may contribute to protection beyond intensity alone[10,62]. Recent developments have led to the availability of objective and non-invasive biomarkers of cumulative solar exposure, foremost being the conjunctival ultraviolet autofluorescence area, which has become a reliable quantitative measure and has shown significantly decreased values in myopic children compared to their non-myopic counterparts, thus providing a novel tool for the accurate quantification of outdoor exposure to allow evaluation of the efficacy of interventions in future clinical trials and epidemiological studies[63]. Evidence quality for the overall protective effect of increased outdoor time is high, supported by consistent findings from randomized and longitudinal studies, although the precise contributions of individual mechanisms whether dopamine-mediated, spectral, vitamin D-related, or optical remain moderate quality due to reliance on animal models and observational human data[2,63-64]. Confounding factors, including concomitant near-work activities, urbanization, socioeconomic factors, and variability in measurement are the conditions that must be carefully controlled, and standardization of outdoor exposure evaluation using biomarkers such as conjunctival ultraviolet autofluorescence (CUVAF) area or portable light sensors for improving causal status and the effectiveness of preventive measures. Overall, the advocacy of outdoor activity as a preventive measure for myopia is a mainstay of public health strategies for targeting myopia, especially in schools where regular outdoor breaks are in their policies and schools have access to green spaces and organize structured light exposure, and thus offers a viable, evidence-based, and scalable solution for curbing the worldwide growing epidemic of childhood myopia.

Screen time and digital device use Prolonged screen time has been increasingly investigated as a potential modifiable risk factor for myopia onset and progression in school-aged children, particularly since the COVID-19 pandemic accelerated digital device use[65-67]. Recent systematic reviews and Meta-analyses report that >2–3h of daily recreational screen time is associated with higher myopia prevalence and faster progression, with pooled odds ratios of 1.3–2.0 for excessive use[14,68-69]. Mechanisms may include reduced viewing distance, decreased blink rate leading to dry eye and visual fatigue, peripheral defocus, and displacement of outdoor time[65].

COVID-19 home confinement studies showed marked increases in myopia progression: Chinese schoolchildren experienced 140%–300% higher incidence in young ages (6–8y) and -0.3 D greater myopic shift during lockdowns[70-71]. Children on low-dose atropine therapy also showed accelerated progression (43% higher) and axial elongation (25% higher) during this period, particularly in elementary students[2].

Some large cohort studies find no independent causal link between screen time and myopia after adjusting for near-work and outdoor activity[72-74]. Evidence quality is moderate: most data are observational or cross-sectional, with self-reported screen time and confounding by educational near-work[14,65]. Randomized trials are limited, though preliminary data suggest limiting recreational screen time to <2h/d and enforcing 20-20-20 breaks may mitigate progression[75].

The World Health Organization recommends <1h of sedentary screen time for children aged 1–5y, and many Chinese schools have implemented policies restricting device use as part of myopia prevention[76-77]. While screen time alone may not fully explain the myopia epidemic (which predates widespread digital device use), it likely exacerbates risk when combined with low outdoor time and high near-work. Policies limiting digital device usage, when integrated into comprehensive myopia prevention initiatives alongside outdoor promotion and near-work regulation, represent a practical and scalable public health strategy for reducing myopia risk in school-aged children[76].

Diet and nutrition Dietary factors represent an emerging area of interest as potentially modifiable influences on childhood myopia, though evidence remains inconsistent and of moderate to low quality[2,10,14]. Recent systematic reviews and Meta-analyses have explored associations between macronutrients, micronutrients, obesity, and refractive error.

Higher consumption of refined carbohydrates and high glycemic index/load diets has been associated with increased myopia risk in some observational studies, particularly among girls, possibly through insulin-mediated effects on scleral growth or inflammation[78]. Conversely, whole grain intake of more than 50% of total grain consumption has been identified as an independent protective factor against myopia in primary school-age children, suggesting that the form of carbohydrate consumed, rather than carbohydrate intake alone, may modulate myopia risk[79-80]. However, other large cohort studies (*e.g.*, GUSTO) found no significant link between carbohydrate intake and spherical equivalent or axial elongation[81]. Evidence quality is moderate at best, with most data cross-sectional and confounded by socioeconomic and lifestyle factors.

Childhood obesity is linked to higher myopia prevalence and severity in several population-based studies, with obese children showing 3–5 times greater odds of high myopia (stronger in girls)[82]. Potential mechanisms include insulin resistance, altered growth hormone signaling, and increased axial length[83].

Micronutrients show mixed results. Low serum vitamin D has been associated with longer axial length and higher myopia risk in some cohorts, possibly *via* effects on scleral remodeling[84], but findings are inconsistent across studies[85-86], Vitamin A and omega-3 polyunsaturated fatty acids (including DHA) have been hypothesized to protect against myopia through anti-inflammatory and choroidal blood flow effects, but large-scale evidence is limited and conflicting[87-88]. Overall, current evidence is insufficient to establish diet as a strong, independent risk factor or preventive target. Confounding by education, near-work, outdoor time, and socioeconomic status remains a major limitation. High-quality longitudinal studies and randomized trials are needed to clarify potential mechanisms and clinical relevance.

Sleep Emerging evidence links insufficient sleep and disrupted circadian rhythms to increased myopia risk and progression in school-aged children[89-91]. Recent systematic reviews and Meta-analyses consistently show that shorter sleep duration (<9h/night) is associated with higher myopia prevalence and faster progression, with pooled odds ratios ranging from 1.2 to 1.8 per hour of reduced sleep duration[89-90], and cross-sectional studies from China, Republic of Korea, and Japan report that adolescents with late bedtimes or poor sleep quality exhibit greater myopic shifts, even after adjusting for near-work and outdoor time[2,14,92].

Possible explanations for this effect are that disrupted circadian patterns and/or changes in melatonin secretion also play a role in the regulation of the development of the eye and scleral remodeling[57]. According to animal studies, there is evidence that disruptive circadian rhythms promote axial elongation, while suppression of melatonin signaling appears to exacerbate experimental myopia[93]. In humans, exposure to screens in the evenings (blue light) is thought to delay the onset of melatonin; therefore increasing potential for risk[94].

The quality of existing evidence is regarded as moderate, given that most of the data was derived from observational studies with self-reported sleep-related outcomes and potential confounding factors associated with lifestyle (*e.g.*, academic pressure and screen time)[89-91]. Few interventional studies exist, though preliminary trials improving sleep hygiene show modest benefits on refractive error progression[88]. Although there is still a lack of definitive causal relationships[89], sleep hygiene is viewed as a plausible and modifiable treatment option to consider along with other proven methods (*e.g.*, regulating near-task time and spending time outdoors)[90]. Further longitudinal and randomized trials are needed to clarify its independent contribution.

Other Factors

Parental myopia While there is strong evidence for genetic involvement, the rapid rise in myopia prevalence, particularly in Southeast Asia[95], cannot be attributed solely to genetic changes, emphasizing the importance of gene-environment (G×E) interactions[2,4]. Recent advances have identified multiple genetic loci (*e.g.*, APLP2, ZMAT4, PIK3CG-PRKAR2B) that interact with environmental exposures such as education and near-work, with replicated effects showing greater genetic risk in high-education environments[10,96-97]. However, G×E research remains challenging due to measurement imprecision in near-work and outdoor time, and only a subset of loci has shown consistent replication[98].

Parental myopia is one of the strongest and most consistent risk factors for childhood myopia, with a dose-dependent effect: children with one myopic parent have approximately 2–3 times higher risk, and those with two have 6–8 times higher risk compared to children with non-myopic parents[99-102]. This association persists across diverse ethnic groups, even after adjusting for inherited myopia-related single-nucleotide polymorphisms (SNPs), suggesting independent contributions from shared environment and lifestyle[99-100]. Myopic parents tend to be, on average, more educated, which may contribute to fostering a lifestyle that increases myopia risk[103]. This includes habits such as higher engagement in near-work activities and less time spent outdoors[104].

In high-prevalence populations (*e.g.*, urban East Asia), the relative risk from parental myopia is somewhat attenuated, likely because environmental factors dominate once baseline prevalence is high[105]. Monogenic syndromic forms of myopia are rare, but in common non-syndromic school-age myopia, parental history remains a key predictor independent of genetics[2]. These findings underscore the need for precise measurement of near-work, outdoor time, and other modifiable factors to better disentangle genetic and environmental contributions.

DISCUSSION

Environmental and lifestyle factors interact synergistically to contribute to the onset and progression of myopia in children aged between school-age years, with less outdoor time, more time on near-work, increasing screen time, urbanization and disrupted sleep as coupled rather than individual risk factors[2,14]. The protective effect of outdoor time is frequently attenuated when combined with high near-work exposure or limited green space access, as demonstrated in longitudinal cohorts where childhood outdoor activity deficits compounded by increased reading and digital device use were associated with a substantially higher likelihood of developing high myopia in adulthood[106-108]. Urbanization further contributes to this behavior by limiting outdoor activities, promoting indoor activities, and increasing academic stress, which in turn lead to an accumulation of near-work load and decrease natural light exposure[10,13]. Geographical patterns also exemplify such synergies: East and Southeast Asia continually document the highest prevalence of childhood myopia (35%–47% in recent Meta-analyses), due mainly to concentrated educational practices, urban lifestyle restricting open space access and stimulating close-up work[3,54,58]. Age modulates these effects, with early childhood and elementary years showing stronger associations between near-work, educational demands, and myopia development, while adolescence may exhibit more stable progression in some settings[2]. Emerging evidence also highlights sleep deprivation as a contributing factor, with Meta-analyses linking insufficient sleep (<9h/night) to increased myopia risk (pooled OR 1.2–1.8 per hour reduction), potentially through disrupted circadian rhythms, melatonin dysregulation, and altered scleral remodeling[89-91]. Urban environments further compound sleep disruption via artificial nighttime light exposure, creating a vicious cycle with screen time and academic pressure[57].

Myopia prevention and control must therefore adopt a multifaceted, evidence-based approach targeting these modifiable factors, with a strong emphasis on early intervention during school-aged years when ocular growth is most plastic[2]. Promoting outdoor activity remains the most robustly supported strategy: RCTs and large-scale school programs in Taiwan Province of China, Singapore, and mainland China have demonstrated significant reductions in myopia incidence (up to 50%) and progression rates through mandated outdoor recess or structured outdoor time, likely *via* light-stimulated dopamine release inhibiting axial elongation[55,109-110]. The latest objective biomarkers like (CUVAF) confirms reduced cumulative sunlight exposure in myopic children and provides an effective tool for monitoring compliance and evaluating intervention efficacy[63]. Near-work and screen-time management are complementary: evidence supports limiting continuous close work (>30–45min at <30 cm), enforcing the 20-20-20 rule, maintaining viewing distances ≥30–40 cm, and restricting recreational screen time (<2h/d), particularly when combined with increased outdoor exposure[65]. Wearable devices, such as Clouclip have shown utility in real-time tracking and behavioral feedback, improving near-work habits and visual break adherence in pilot studies[111-112]. Sleep hygiene interventions encouraging 9–11h of sleep per night, reduced evening screen time, and consistent bedtime routines represent low-cost strategies, though high-quality RCTs are still lacking to confirm their independent effects[89-90]. Nutritional and obesity prevention strategies remain supportive rather than primary, with balanced diets and weight management potentially mitigating insulin resistance and inflammatory pathways implicated in progression[80,82]. Parental myopia, as a key genetic-environmental risk factor, warrants early screening and targeted lifestyle education to promote a balance between outdoor activity and near-work exposure[99-100].

Novel therapeutic approaches further expand prevention options. Low-level red-light therapy (RLRL, 650–680 nm) shows promise in modulating circadian rhythms, reducing oxidative stress, and influencing scleral remodeling genes, with multicenter RCTs demonstrating axial shortening in high myopia[113-114]. Emerging evidence also implicates inflammation [*e.g.*, tumor necrosis factor-α (TNF-α), interleukin-6 (IL-

6)] and gut microbiota in progression, suggesting anti-inflammatory or microbiome-targeted strategies as future directions[115]. Gene therapy and epigenetic modulators (*e.g.*, DNA methyltransferase inhibitors) represent long-term frontiers, though clinical translation remains distant[116].

This narrative synthesis has inherent limitations, including possible subjectivity in study selection, lack of formal systematic methodology, lack of formal quality assessment and possible exclusion of non-English publications. Bias may be introduced by the use of heterogeneous observational data or through different study designs and as well as by the small number of participants in some of the studies included. However, actionable, evidence-based strategies can be implemented at the school, family, and public health policy levels to reduce childhood myopia. These strategies will include promoting outdoor activity, regulating near-work, and managing screen time. Current evidence for implementing these strategies is now available and should be committed to addressing the increasing worldwide prevalence of myopia.

CONCLUSION

This review demonstrates that childhood myopia is driven by a complex, synergistic web of modifiable environmental and lifestyle factors, with the strongest protection arising from early, sustained increases in outdoor time and reductions in cumulative near-work exposure. Interventions targeting these factors particularly school-based outdoor programs, screen-time limits, and sleep hygiene offer practical, scalable ways to slow onset and progression. Emerging technologies such as wearable monitoring and biomarkers (*e.g.* CUVAF) could help increase compliance and precision, and comprehensive policy changes in the areas of education, urban design, and digital behaviors are necessary to reverse current trends. Given the escalating global prevalence and long-term risks of high myopia (retinal complications, vision loss), prioritizing these evidence-based strategies in childhood represents an urgent public health priority. Coordinated efforts across families, schools, clinicians, and policymakers can substantially reduce the future burden of myopia and safeguard vision for coming generations.

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