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SYSTEMATIC REVIEW

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Association of physical activity, sedentar y behaviour, sleep and myopia in children an d adolescents: a systematic review and dose -response meta-analysis

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Abstract

Purpose This study aimed to systematically evaluate the dose-response relationships between physical activity (PA), sedentary behavior(SB) (including near work [NW] and screen time [ST]), sleep duration (SD), and myopia risk among children and adolescents.

Design Systematic review and dose-response meta-analysis.

Methods We systematically searched PubMed, EMBASE, Cochrane Library, and Web of Science up to November 19, 2024. Methodological quality was assessed using Joanna Briggs Institute (JBI) and ROBINS-I tools. Random-effects meta-analyses were used to estimate categorical and continuous dose-response relationships. Subgroup analyses and sensitivity analyses were performed to explore heterogeneity sources and test robustness.

Results A total of 45 observational studies (766,848 participants aged 5–19 years) were included. Categorical analyses showed that, compared with the lowest exposure categories, higher PA levels (highest: OR = 0.77, 95% CI: 0.63–0.96; intermediate: OR = 0.76, 95% CI: 0.63–0.93) and longer SD (highest: OR = 0.67, 95% CI: 0.48–0.92; intermediate: OR = 0.82, 95% CI: 0.73–0.92) significantly reduced myopia risk. Conversely, higher levels of NW (highest: OR = 1.71, 95% CI: 1.28–2.27; intermediate: OR = 1.34, 95% CI: 1.19–1.50) and ST (highest: OR = 1.59, 95% CI: 1.14–2.22; intermediate: OR = 1.29, 95% CI: 1.12–1.49) were associated with significantly increased risk. In the continuous dose-response meta-analysis, a linear association was observed between PA, ST, and myopia. Each additional hour of PA per day reduced the risk of myopia by 12%, while each additional hour of ST increased the risk by 31%. Nonlinear associations were found between NW, SD, and myopia. Among children and adolescents, 1.5 and 2.5 h/day of NW increased the risk of myopia by 25% and 29%, respectively. Although longer SD was associated with a reduced risk of myopia, this effect did not reach statistical significance at any exposure level.Subgroup analyses revealed that protective effects of PA were more evident in low- and middle-income countries, smaller sample sizes, and cross-sectional studies, while increased risks related to ST and NW were stronger in low-income settings. No subgroup significantly modified the association between SD and myopia risk.

Conclusion Increasing PA, while limiting ST and NW, effectively reduces the risk of myopia among children and adolescents. The association between sleep duration and myopia remains inconclusive, warranting further investigation.

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Keywords Physical activity, Sedentary behaviour, Sleep duration, Myopia, Children and adolescents, A systematic review, Dose-response meta-analysis

Introduction

Myopia, also known as short-sightedness or near-sightedness, is a refractive error that typically begins in childhood and early adulthood [1, 2]. It occurs when the refractive power of the cornea and lens is not matched to the axial length of the ocular globe, causing images of distant objects to be focused in front of the retina and resulting in blurred distance vision [3, 4]. Myopia poses a considerable threat to global eye health, and its prevalence continues to rise [5–7]. This increase imposes an escalating global financial burden (i.e., healthcare expenditure and loss of productivity) [8], and elevates the risk of eye diseases such as retinal detachment, cataracts, and glaucoma [9]. By 2050, the global prevalence of myopia is projected to surpass 740 million cases [10].Consequently, making myopia a significant global public health challenge.

Although myopia has a strong hereditary component, lifestyle factors also play a pivotal role in its development [11, 12]. Understanding the factors contributing to myopia onset is essential for reducing its incidence and slowing its progression. Within a 24-h cycle, physical activity (PA), sedentary behavior (SB), and sleep duration (SD) interact closely with circadian rhythms [13, 14].Circadian rhythms play a pivotal role in regulating ocular physiology and may influence the development and progression of myopia [15, 16]. Research indicates that each hour of reduced sleep can disrupt nighttime ocular processes and potentially accelerate myopia onset, particularly when coupled with nighttime light exposure that suppresses melatonin [17]. Adequate sleep helps maintain cyclical changes in intraocular pressure and axial length [18], while daytime PA, especially outdoors, supports healthy circadian patterns through exposure to natural light [19]. Conversely, sedentary activities performed at night can further disturb circadian function by limiting daytime light exposure and introducing artificial light that may inhibit melatonin secretion [20]. Thus, strategies emphasizing sufficient sleep, regular outdoor activity, and minimized nighttime screen use could collectively mitigate myopia risk by preserving normal circadian rhythms [5, 19, 21, 22].Meta-analyses have investigated the associations between motor behavior and the incidence, prevalence, and progression of myopia in children and adolescents. The majority of findings suggest that increased PA [23, 24], reduced SB [25, 26],and sufficient SD [27] are associated with a lower risk of myopia, while only a small number of studies have shown no association [28–30]. However, these studies only combined high and low effect sizes of PA, SB, and SD, and there is insufficient evidence to support that specific daily limits can reduce myopia incidence or prevalence. Additionally, there is a lack of continuous dose–response meta-analysis.

Given the lack of rigorous analysis of the available evidence, we aimed to assess the categorical and continuous dose-response associations between PA, SB, SD, and the incidence or prevalence of myopia in children and adolescents through systematic reviews and meta-analyzes of observational studies on the following questions:(1) Is there a linear or nonlinear dose-response association? (2) At what level of daily exposure do PA, SB, and SD significantly increase the risk for the incidence or prevalence of myopia?

Methods

The research protocol for this systematic review has been prospectively registered in the PROSPERO international systematic review registry (registration number: CRD42024627651). This review follows the MOOSE guidelines [31] for meta-analysis of observational studies and the PRISMA guidelines [32] for systematic reviews and meta-analyses14.

Search methods for identifying studies

The systematic search included the period from the inception of each database to November 19, 2024, and was conducted in four electronic databases: PubMed, EMBASE, The Cochrane Library, and Web of Science. The search terms included “myopia,” “exercise,” “sedentary behavior,” and “sleep.” The full search strategy can be found in Table S1.

Eligibility criteria for considering studies for this review

The inclusion criteria for the article were as follows: (1) Children and adolescents aged 5 to 19 years (2) PA, SB and SD as exposure factors and using a subjective or objective quantification of total daily or weekly time (3) Criteria defining myopia, with cycloplegia refraction or non-cycloplegia refraction measurements performed by ophthalmologists/optometrists, and myopia incidence or prevalence as an outcome indicator. (4) Prospective studies, cross-sectional studies, cohort studies (5) OR and 95% CI reported or sufficient data provided to calculate these values (6) Studies in English. Exclusions: (1) Participants younger than 5 or older than 19 years with eye disease or previously treated for myopia (2) Detailed information on daily/weekly physical activity, sedentary behavior, sleep duration, etc. was not provided. (3) Undefined criteria for myopia or self-reported myopia (4) Data types that could not be converted to OR and 95% CI (5) Abstracts, experimental studies, animal studies, systematic reviews or studies that were not written in English.

Study selection

Two independent researchers (D.H.M. and J.L.Q.), independently screened titles and abstracts using EndNote (version: X20, Clarivate Analytics, Philadelphia, USA) against the inclusion and exclusion criteria. After comparing the screening results and clarifying any discrepancies, the full-text articles were obtained. Subsequently, the two reviewers independently reviewed the full-text articles and clarified any discrepancies through in-depth discussions.

Data collection

Data extraction was performed independently by two reviewers. The following variables were extracted: study background, population characteristics, study design, Exposure factors, outcome, and associations of exposure factors with outcome measures.

Risk of bias assessment

The methodological quality and risk of bias of the included studies were evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal Checklists for Cross-Sectional and Cohort Studies [33]. For cross-sectional studies, the JBI tool comprises eight items that assess aspects such as the study subjects, disease conditions, influencing factors, confounders, and data analysis. For cohort studies, the JBI tool includes 11 items, focusing on study design, control of confounding factors, and the measurement of outcome indicators. Each item is rated as "yes," "no," "unclear," or "not applicable." To provide a more objective and nuanced quality assessment, we also employed the ROBINS-I tool for quantitative risk of bias evaluation (Table S2) [34]. This dual approach addresses the limitations inherent in using the JBI tools alone and enhances the overall reliability of our quality assessment.

Data synthesis and analysis

Evaluation of the exposure

The exposures of interest for this study were PA, SB, and SD.PA is defined as any bodily movement produced by skeletal muscles that requires energy expenditure [35].In this study, PA refers to the total daily duration of physical activity, regardless of the context in which it occurs, thereby providing a comprehensive representation of overall PA levels. SB is defined as any waking behavior characterized by an energy expenditure of 1.5 metabolic equivalents (METs) or lower while sitting, reclining, or lying down [35]. In this study, SB encompassed both NW and ST. NW represents the total daily time spent on short-distance activities such as reading and studying, whereas ST refers to the total daily time spent in front of an electronic screen, including television viewing, computer use, etc [36]. SD is defined as the total time spent asleep within a 24-h period [37].

All studies included in this study used time spans to assess the association between the exposure factors (PA, SB, and SD) and the outcome indicators (myopia incidence or prevalence). The midpoints of the upper and lower boundaries were used to estimate the mean time. For open-ended intervals at the highest level, the interval was estimated by assuming that its length was equivalent to that of its adjacent interval; for open-ended intervals at the lowest level, the lower bound was assumed to be 0 [38, 39]. The estimated median times and the detailed reporting times for each exposure factor are presented in Table S3.

Categorical dose-response meta-analysis

Based on the described method, each exposure factor was divided into three categories (highest, middle, and lowest) [38–40]. For studies with three time levels, these levels were assigned to the highest, middle, and lowest categories, respectively. For studies with two time levels, the lowest level was assigned to the lowest category, while the higher level was compared to the highest and middle categories, and the appropriate category was selected based on similarity. For studies with more than three time levels, the lowest level corresponded to the highest category, and the remaining levels were classified according to their similarity with the highest and middle categories. The median duration and interquartile range for each time category were calculated to verify that there was no overlap between categories. The classification for each article is shown in Table S3.To address potential subjectivity and enhance the credibility of our classification thresholds, we conducted sensitivity analyses using guideline-based cutoff points selected a priori from authoritative public health recommendations. Specifically, physical activity was categorized as <60 vs. ≥ 60 min/day of moderate-to-vigorous intensity based on World Health Organization (WHO) guidelines for children and adolescents; screen time was classified as <2 vs. ≥ 2 h/day for recreational activities following the 24-h Movement Guidelines; and sleep duration was categorized as <8 vs. ≥ 8 h/night according to National Sleep Foundation (NSF) recommendations. These sensitivity analyses aimed to determine whether alternative thresholds would yield consistent results, thereby confirming the robustness, interpretability, and clinical applicability of our findings. Due to the absence of official standards, sensitivity analyses were not conducted for the near-work exposure.

Categorical dose–response meta-analysis was performed. By comparing the lowest category with the middle and highest categories, the combined effect values between the different exposure factor categories and myopia incidence or prevalence were calculated, and forest plots were generated. Given the potential variation in true effect sizes across studies, a random-effects model was employed as the primary approach, following the recommendations of Borenstein et al [41]. Study heterogeneity was assessed using the I^2 statistic and τ^2 estimation, but model selection was not solely based on I^2 values. Publication bias was evaluated using funnel plots and the Egger test. For cases with significant publication bias, the trim-and-fill method was applied [42].

Subgroup analyses by age, country income level, sample size, study type, myopia definition, use of cycloplegia, and ROBINS-I risk of bias were conducted to further explore the relationship between exposure factors and myopia incidence or prevalence [43].Independent sensitivity analyses were carried out on key subgroups and on studies with extremely high prevalence rates or large sample sizes to confirm the robustness of the findings [44]. Additionally, When significant interactions between subgroups were observed, multivariate meta-regression was performed to assess moderator interactions [45]. Adjusted for age, use of cycloplegia, and ROBINS-I risk of bias. All analyses were conducted using R (version 4.3.3), employing the META and metafor packages.

Continuous dose-response meta-analysis

A continuous dose–response meta-analysis was performed to investigate the association between each additional hour per day of various exposure factors and the incidence or prevalence of myopia, using the GLST package in Stata [46].A random-effects model was employed to account for between-study heterogeneity while estimating the associations between different exposure factors and the incidence or prevalence of myopia [47]. Restricted cubic splines with three predefined knots (positioned at the 25th, 50th, and 75th percentiles) were utilized to evaluate potential linear and nonlinear dose–response relationships [48].Generalized least-squares regression was employed to estimate the dose–response associations within individual studies, quantifying the risk of myopia incidence or prevalence per additional hour per day of PA, SB, and SD.

Results

Characteristics of included studies

The initial search identified 3,062 articles. Following the removal of duplicates, title and abstract screening, and full-text review based on inclusion criteria, 45 studies were included in the final analysis (Fig. 1). Among these, 39 were cross-sectional studies [36, 49–86], and 6 were prospective cohort studies [87–92] with follow-up periods ranging from 2 to 10 years. The total sample comprised 766,848 children and adolescents aged 5–19 years, with studies published between 2004 and 2024. The majority of studies were conducted in China ($n = 24$, 43.5%) [36, 50, 51, 53, 54, 56, 57, 59–68, 70, 74, 75, 80, 85, 90, 91], The studies originated from a diverse range of countries. Specifically, two studies were conducted in Pakistan [49, 81], South Korea [58, 76], Ethiopia [71, 73], Denmark [89, 92], and the United States [78, 82]. In contrast, single studies were reported from Malaysia [52], Estonia [55], Germany [87], Kazakhstan [69], Poland [72], Australia [88], Vietnam [77], Saudi Arabia [79], Northern India [83], Northern Ireland [84], and Singapore [86]. One study objectively assessed SB and PA using accelerometers [92], while the others relied on self-reported questionnaires completed by guardians or the participants themselves. Definitions of myopia varied across studies, and all studies involved refraction measurements performed by ophthalmologists or optometrists, with 24 studies employing cycloplegic refraction [36, 49, 55, 60, 64, 66, 68–73, 75, 77, 79, 80, 82–85, 88, 90–92]. In the study by L. Huang, the highest myopia prevalence was observed (85.23%) [70], while the study by X.N. Liu reported the lowest prevalence (6.77%) [75]. The key characteristics of the included studies are summarized in Table 1.

Association between PA and myopia incidence and prevalence

A total of 6 cohort studies [87–92]and 20 cross-sectional studies [36, 50–52, 54–57, 62, 63, 66, 67, 69, 74, 77, 80–83, 85]reported categorical associations between PA and the incidence or prevalence of myopia in children and adolescents. Compared with the lowest PA category, both the highest category [OR: 0.77; 95% CI: 0.63, 0.96; $I^2 = 79$] (Figure S1) and the intermediate category [OR: 0.76; 95% CI: 0.63, 0.93; $I^2 = 89$] (Figure S3) were significantly associated with a reduced risk of myopia incidence and prevalence. Egger's test indicated no significant publication bias (highest category:$P = 0.5979$) (Figure S2) or the (intermediate category:$P = 0.4303$) (Figure S4). To strengthen the credibility of our findings, we applied the WHO recommended threshold of < 60 vs. ≥ 60 min/day of moderate-to-vigorous intensity PA. The analysis revealed that participants engaging in ≥ 60 min/day of PA

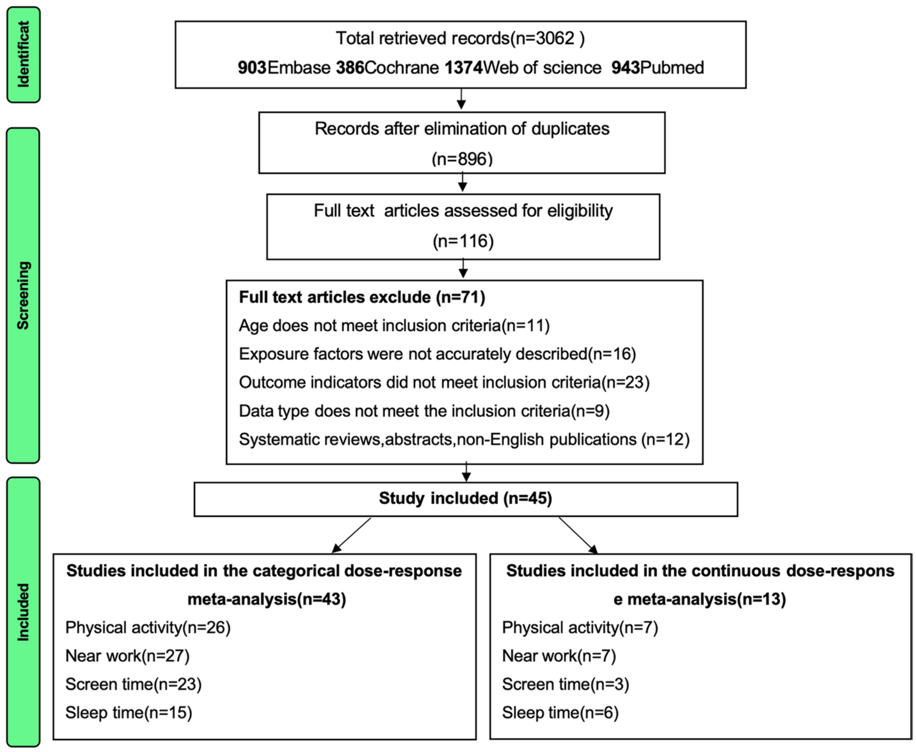

Fig. 1 Flow diagram of the study selection process

had significantly lower odds of myopia (OR: 0.77; 95% CI: 0.67–0.89) compared to those with less activity, supporting the robustness of our results (Figure S5).

Subgroup analyses (Table S4) revealed significant interactions ($P < 0.05$) between income level, study type, and both the intermediate and highest PA categories, whereas sample size and myopia definition exhibited significant interactions only in the intermediate category. Lower myopia incidence or prevalence was associated with studies conducted in low-income and middle-income countries, cross-sectional study designs, smaller sample sizes (< 1000), and when myopia was defined as SE ≤ −0.5. Separate sensitivity analyses were conducted for subgroups with significant interactions and for groups with high prevalence (> 70%) to test the robustness of our findings (Figure S5). In the moderate PA category, pooled results based on the "≤ −0.5" myopia definition, high- and middle-income countries, cross-sectional studies, low prevalence, and large sample sizes (≥ 1000) showed only minimal fluctuations when individual studies were excluded. In contrast, associations were less robust for the "other conditions" myopia definition, low-income country subgroups, cohort studies, high prevalence, and small sample sizes (< 1000). In the highest PA category, results for middle-income countries, cross-sectional studies, and low prevalence were robust, whereas those for high-income countries, cohort studies, and high prevalence groups were less robust. Furthermore, multivariable meta-regression analysis—adjusted for age, use of cycloplegia, and ROBINS-I risk of bias—revealed that the association between PA category (intermediate and highest) and myopia prevalence was not statistically significant across different subgroups (i.e., country income level, study type, sample size, and myopia definition) (Table S8).

Seven studies [51, 54, 55, 57, 63, 85, 89] were included in the continuous dose–response meta-analysis. This analysis revealed a significant linear association between PA and the incidence or prevalence of myopia (P linearity = 0.003; P non-linearity = 0.0538) (Fig. 2). Each additional hour of PA per day was associated with a 12% reduction in the risk of myopia [OR: 0.88; 95% CI: 0.81, 0.96; $I^2 = 79.6$].

Association between SB and myopia incidence and prevalence

Near work

Four cohort studies [87, 88, 90, 91] and 23 cross-sectional studies [49–51, 53–55, 57–59, 62–64, 69, 71, 72, 74, 76, 77, 79, 83–86] reported categorical associations between NW and the incidence or prevalence of myopia in children and adolescents. Compared with the lowest NW

Table 1 Characteristics of included studies (n = 45)

Study (first author, year, country)	Type of study (Length of Follow-up)	Age (years)	Total Sample size	Exposure	Exposure description	Definition of myopia	Whether use of cycloplegia	Incidence/ Prevalence of Myopia
M.Ali 2019 [49] Pakistan	Cross-sectional study	6–12	2936	Near work Screen time	Questionnaire	>0.50D	YES	57.93%
L.J.Zhao 2024 [50] China	Cross-sectional study	5–18	31880	Near work Screen time Sleep time Physical activity	Questionnaire	≤−0.50D	NO	55.3%
L.Ye 2024 [51] China	Cross-sectional study	11.2	6832	Near work Screen time Physical activity	Questionnaire	≤−0.50D	NO	70.7%
H.J. Wardati 2024 [52] Malaysia	Cross-sectional study	9.53±1.69	480	Screen time Physical activity	Questionnaire	<−0.50D	NO	7.1%
Y.Wang 2024 [53] China	Cross-sectional study	5–19	34138	Near work Screen time	Questionnaire	<−0.50D	NO	65.65%
J.Y. Wang 2024 [54] China	Cross-sectional study	5–19	6187	Near work Screen time Sleep time Physical activity	Questionnaire	≤−0.50D	NO	71.4%
T.Palumaa 2024 [55] Estonia	Cross-sectional study	16.7±0.41	123	Near work Screen time Physical activity	Questionnaire	≤−0.50D	YES	30.9%
F.MA 2024 [56] China	Cross-sectional study	8.82	2976	Physical activity	Questionnaire	≤−0.50D	NO	52.92%
R. L. Li 2024 [57] China	Cross-sectional study	12,15	451， 387	Near work Screen time Sleep time Physical activity	Questionnaire	≤−0.50D	NO	49.3% 50.7%
J.M. Kim 2024 [58] Korea	Cross-sectional study	9.00±1.94	24345	Near work	Questionnaire	≤−0.50	NO	61.38%
Z.H. Huang 2024 [59] China	Cross-sectional study	13.63±1.11	126375	Near work Screen time Sleep time	Questionnaire	<−0.50D	NO	71.34%
Y.Huang 2024 [60] China	Cross-sectional study	9.26±1.49	857	Sleep time	Questionnaire	≤−0.50D	YES	63.6%
Z.R. Gao 2024 [61] China	Cross-sectional study	12.08±2.12	3138	Sleep time	Questionnaire	≤−0.50D	NO	80.1%
X.H. Fang 2024 [62] China	Cross-sectional study	6–18	346146	Near work Physical activity	Questionnaire	≤−0.50D	NO	56.8%
D.Zhang 2023 [63] China	Cross-sectional study	11.9	34644	Near work Screen time Sleep time Physical activity	Questionnaire	≤−0.50D	NO	60%
W.Peng 2023 [64] China	Cross-sectional study	7–12	974	Near work	Questionnaire	<−0.50D	YES	27.1%
J. Lin 2023 [65] China	Cross-sectional study	13.6±2.6	9327	Sleep time	Questionnaire	<−0.50D	NO	75.4%
P.Cheng 2023 [66] China	Cross-sectional study	7–9	1722	Screen time Sleep time Physical activity	Questionnaire	≤−0.50D	YES	25.6%

Table 1 (continued)

Study (first author, year, country)	Type of study (Length of Follow-up)	Age (years)	Total Sample size	Exposure	Exposure description	Definition of myopia	Whether use of cycloplegia	Incidence/ Prevalence of Myopia
W.F. Zhu 2022 [67] China	Cross-sectional study	13.5 ± 2.8	8506	Physical activity	Questionnaire	≤−0.50D	NO	
X.X. Zhao 2022 [68] China	Cross-sectional study	13.48±3.11	11011	Sleep time	Questionnaire	≤−0.50D	YES	75.7%
C.Y. Wang 2022 [36] China	Cross-sectional study	5.15 ± 0.37	23 930	Screen time Physical activity	Questionnaire	≤−0.50D	YES	10.7%
D.Philipp 2022 [87] Germany	Prospective cohort study 10-year	7.3/14.9	1437	Near work Physical activity	Questionnaire	≤− 0.75 D	NO	3.9% 21.5%
A.Mukazhanova 2022 [69] Kazakhstan	Cross-sectional study	11.2 ± 3.6	2293	Near work Screen time Physical activity	Questionnaire	≤−0.50D	YES	28.3%
L.Huang 2022 [70] China	Cross-sectional study	12 （9–14 ）	1140	Sleep time	Questionnaire	≤−0.50D	YES	85.23
E.A.Gebru 2022 Ethiopia	Cross-sectional study	16.90±1.32	349	Near work	Questionnaire	≤−0.50D	YES	16.05%
D.Czepita 2010 [72] Poland	Cross-sectional study	6–18	5865	Near work Screen time	Questionnaire	<−0.50D	YES	12.44
A.N.French 2013 [88] Australia	longitudinal cohort study 5-6year	6,12	2059	Near work Physical activity	Questionnaire	≤−0.50D	YES	14.8% 17.3%
A.S.Assem 2021 [73] Ethiopia	Cross-sectional study	14–18	601	Screen time	Questionnaire	≥0.50D	YES	8.49%
Z.H. Xie 2020 [74] China	Cross-sectional study	7–13	997	Near work Physical activity Screen time	Questionnaire	<−0.50D	NO	33.9%
X.N. Liu 2020 [75] China	Prospective cohort study 2-year	7.36 ± 0.60	6042	Sleep time	Questionnaire	≤−0.50D	YES	6.77%
H.Kim 2020 [76] Korea	Cross-sectional study	12.2 ± 0.2	983	Near work	Questionnaire	≤−0.50D	NO	65.4%
H.D. Hung 2020 [77] Vietnam	Cross-sectional study	12–16	1987	Near work Physical activity Screen time	Questionnaire	<−0.50D	YES	14.2%
M.H. Hansen 2020 [89] Denmark	Prospective cohort study 5-year	16–17	1443	Physical activity Screen time	Questionnaire	≤−0.50D	NO	25%
S.Y.Chiang 2020 [78] America	Cross-sectional study	15.39 ±0.06	6751	Screen time	Questionnaire	<−1.0D	NO	42.77%
R.Alomair 2020 [79] Saudi Arabia	Cross-sectional study	6–15	850	Near work	Questionnaire	>−0.75D	YES	14.13%

Table 1 (continued)

Study (first author, year, country)	Type of study (Length of Follow-up)	Age (years)	Total Sample size	Exposure	Exposure description	Definition of myopia	Whether use of cycloplegia	Incidence/ Prevalence of Myopia
W. Ku 2019 [90] China	Prospective cohort study 4-year	7–12	1958	Near work Physical activity Screen time	Questionnaire	Prevalent myopia was defined as those who had ≥2 ambulatory care claims . Incident myopia was defined by those who had at least 2 ambulatory care claims after excluding prevalent cases.	YES	Prevalent myopia：26.8% Incident myopia：27.7%
L.S. Qi 2019 [91] China	Prospective cohort study 3-year	14–16	522	Near work Physical activity Sleep time	Questionnaire	≤−0.50D	YES	27.01%
S.X. Liu 2019 [80] China	Cross-sectional study	9.5 ± 2.1	566	Physical activity Sleep time	Questionnaire	<−0.50D	YES	59.2%
N.Ashiq 2019 [81] Pakistan	Cross-sectional study	12.3	168	Physical activity Sleep time	Questionnaire	<−0.75D	NO	15%
Theophanous 2018 [82] America	Cross-sectional study	5–19	60789	Physical activity	Questionnaire	≤−1.0 D	YES	41.9%
Lundberg 2018 [92] Denmark	Prospective cohort study 6-year	15.4 ± 0.7	307	Near work Physical activity	Questionnaire	≤−0.50D	YES	17.9%
R. Saxena 2015 [83] Northern India	Cross-sectional study	11.6 + 2.2	9884	Near work Physical activity Screen time	Questionnaire	<−0.50D	YES	13.1%
L. O'Donoghue 2015 [84] Northern Ireland	Cross-sectional study	12–13	661	Near work	Questionnaire	<−0.50D	YES	17.7%
Y.Y.Lyu 2015 [85] China	Cross-sectional study	7–11	4249	Near work Screen time Sleep time Physical activity	Questionnaire	<−0.50D	YES	36.7%
T. P.L.Quek 2004 [86] Singapore	Cross-sectional study	15–19	946	Near work Screen time	Questionnaire	<−0.50D	NO	73.9%

D Diopter

category, both the highest category and the intermediate category were associated with a significantly higher risk of myopia incidence and prevalence. Specifically, the highest category (Figure S7) [OR = 1.71; 95% CI: 1.28, 2.27; $I^2 = 97$] showed a significantly higher risk compared to the intermediate category (Figure S9) [OR = 1.34; 95% CI: 1.19, 1.50; $I^2 = 91$]. Egger's test indicated significant publication bias for both the highest category ($P = 0.0344$) (Figure S8) and the intermediate category ($P = 0.0350$) (Figure S10).Using the trim-and-fill method to account for potential publication bias, 11 additional studies were imputed for the intermediate category (adjusted OR = 1.02, 95% CI: 0.71–1.46) and 10 additional studies for the highest category (adjusted OR = 1.13, 95% CI: 0.98–1.31). Both results remained statistically non-significant, with high heterogeneity observed in the intermediate category ($I^2 = 97.9\%$) and the highest category ($I^2 = 92.7\%$) (Figure S11).

Subgroup analysis identified a significant interaction only for myopia definition in the highest category ($P < 0.05$), with myopia defined as SE ≤ −0.5 being associated with higher myopia incidence or prevalence

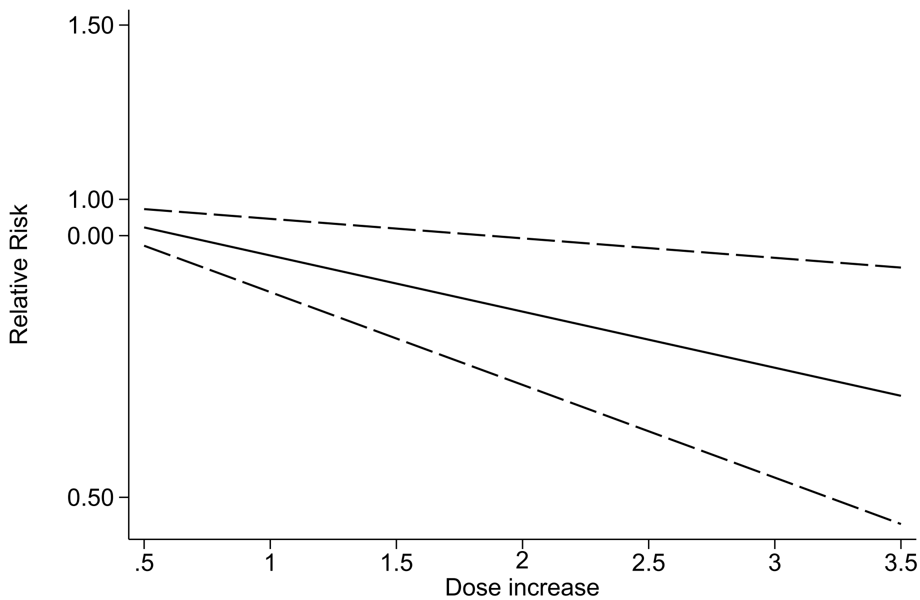

Fig. 2 The continuous dose–response meta-analysis of the association between total physical activity time and the risk of metabolic syndrome

(Table S5). Separate sensitivity analyses were performed for myopia definition (Figure S12), very large sample sizes (> 10,000), and high prevalence (> 70%), and the results indicated that the associations between near work (moderate and highest) and myopia definition (≤ 0.05, other situations), sample size (≤ 10,000, > 10,000), and prevalence (≤ 70%, > 70%) were robust. Multivariate meta-regression analysis (adjusted for age, use of cycloplegics, and ROBINS-I risk of bias) showed that the association between NW category (intermediate and highest) and myopia prevalence across different myopia definition subgroups was not statistically significant (Table S8).

In the continuous dose–response meta-analysis, which included 7 cross-sectional studies [51, 57, 63, 64, 76, 84, 85], a non-linear association between NW and the incidence or prevalence of myopia was observed (P non-linearity = 0.000; P linearity = 0.104) (Fig. 3). For children and adolescents with 1.5 h/day and 2.5 h/day of NW, the

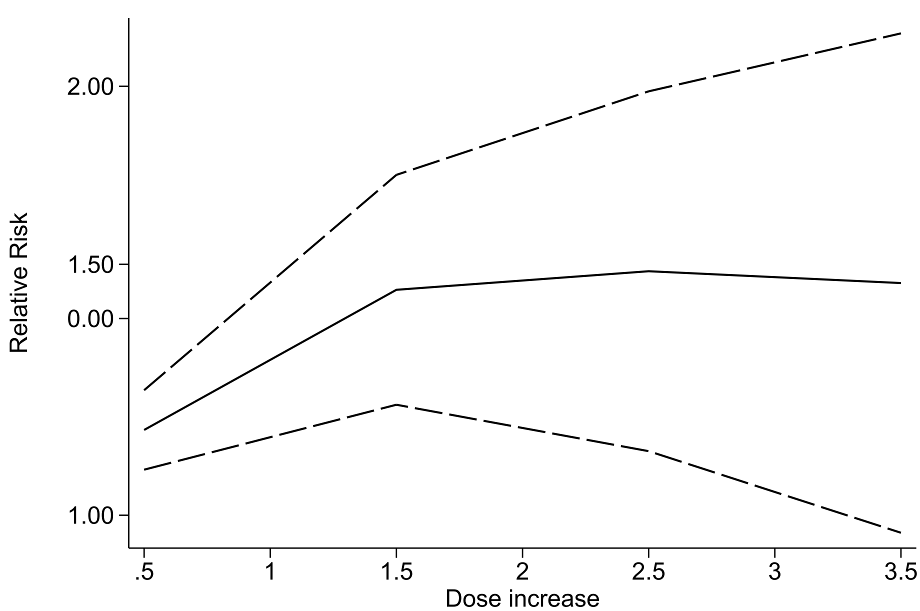

Fig. 3 The continuous dose–response meta-analysis of the association between near-work and the risk of metabolic syndrome

risk of myopia increased by 25% [OR = 1.25; 95% CI: 1.11, 1.42] and 29% [OR = 1.29; 95% CI: 1.03, 1.63], respectively. However, at 3.5 h/day, the association was not statistically significant [OR = 1.27; 95% CI: 0.90, 1.80].

Screen time

2 cohort studies [89, 90] and 21 cross-sectional studies [36, 49–55, 57, 59, 63, 66, 69, 72–74, 77, 78, 83, 85, 86] reported categorical associations between ST and the incidence or prevalence of myopia in children and adolescents. Compared with the lowest ST category, both the highest category and the intermediate category were significantly associated with an increased risk of myopia incidence and prevalence. Specifically, the highest category (Figure S13) [OR = 1.59; 95% CI: 1.14, 2.22; $I^2 = 95$] showed a significantly higher risk than the intermediate category (Figure S15) [OR = 1.29; 95% CI: 1.12, 1.49; $I^2 = 91$]. Egger's test indicated significant publication bias for both the highest category ($P = 0.0388$) (Figure S14) and the intermediate category ($P = 0.0084$) (Figure S16). Using the trim-and-fill method to account for potential publication bias, 12 additional studies were imputed for the intermediate category (adjusted OR = 1.04, 95% CI: 0.88–1.23) and 5 additional studies for the highest category (adjusted OR = 1.10, 95% CI: 0.72–1.69). Both results remained statistically non-significant, with high heterogeneity observed in the intermediate category ($I^2 = 93.6\%$) and the highest category ($I^2 = 96.8\%$)(Figure S17).To enhance the credibility of our categorization, sensitivity analyses were conducted using guideline-based thresholds for screen time established by the 24-h movement guidelines (< 2 vs. ≥ 2 h/day). The results indicated that screen time exceeding 2 h per day was significantly associated with a higher incidence and prevalence of myopia (OR: 1.22; 95% CI: 1.07–1.39) compared to screen time of less than 2 h per day. These findings confirm the robustness of our classification approach(Figure S18).

Subgroup analysis (Table S6) indicated significant interactions based on national income levels ($P < 0.05$), with myopia risk being substantially higher in low-income countries compared with middle-income and high-income countries. Separate sensitivity analyses were performed for country income level and very large sample sizes (> 10,000) (Figure S19). The results demonstrated that in the moderate and highest ST categories, the findings were robust with respect to sample size as well as for high-income and middle-income countries, whereas the findings for low-income countries were not robust. Multivariate meta-regression analysis (adjusted for age, use of cycloplegics, and ROBINS-I risk of bias) showed that the association between the ST category (intermediate and highest) and country income level across different myopia definition subgroups was not statistically significant (Table S8).

In the continuous dose–response meta-analysis, which included 3 cross-sectional studies [51, 54, 57], a highly significant linear association between ST and the incidence or prevalence of myopia was found (P linearity = 0.000; P non-linearity = 0.4509) (Fig. 4). For each additional hour of ST per day, the risk of myopia

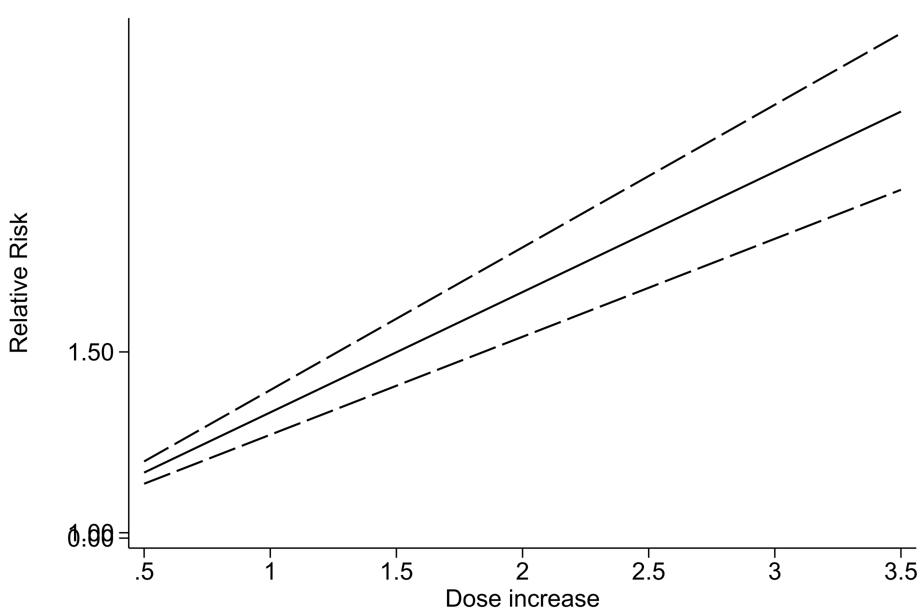

Fig. 4 The continuous dose–response meta-analysis of the association between screen time and the risk of metabolic syndrome

incidence or prevalence increased by 31% [OR = 1.31; 95% CI: 1.25, 1.38; $I^2 = 94.2$].

Association between SD and myopia incidence and prevalence

15 cross-sectional studies [50, 54, 57, 59–61, 63, 65, 68, 70, 75, 80, 81, 85, 91] reported categorical associations between SD and the incidence or prevalence of myopia in children and adolescents. Compared with the lowest SD category, both the highest category(Figure S20) [OR = 0.67; 95% CI: 0.48, 0.92; $I^2 = 80.2$] and the intermediate category(Figure S22) [OR = 0.82; 95% CI: 0.73, 0.92; $I^2 = 77.6$] were significantly associated with a reduced risk of myopia incidence or prevalence. Egger's test indicated significant publication bias for the highest category (Figure S21) ($P = 0.0388$), whereas no significant publication bias was found for the intermediate category (Figure S23) ($P = 0.1373$).Using the trim-and-fill method, 5 additional studies were imputed for highest category (adjusted OR = 0.95, 95% CI: 0.66–1.36), remaining statistically non-significant, with high heterogeneity observed ($I^2 = 86.2\%$) (Figure S24).

Subgroup analysis (Table S7) revealed no significant interactions based on age, sample size, study type, or the use of cycloplegia. Separate sensitivity analyses were performed for very large sample sizes (> 10,000) and high prevalence (> 70%) (Figure S25). The results indicated that in both the intermediate and highest SD categories, the low-prevalence group demonstrated strong robustness, whereas the high-prevalence group was not robust. In the sample size analysis for the intermediate SD category, the results were consistently robust and reliable. To enhance the credibility of our categorization, we performed sensitivity analyses using established guideline-based thresholds for sleep duration recommended by the NSF. The analysis revealed that participants sleeping ≥ 8 h per night had significantly lower odds of incident and prevalent myopia (OR: 0.78; 95% CI: 0.68–0.89; $I^2 = 81.1\%$) compared to those sleeping < 8 h per night, supporting the robustness and consistency of our classification approach (Figure S26).

In the continuous dose–response meta-analysis, which included 6 cross-sectional studies [60, 61, 65, 70, 80, 85], a non-linear association between SD and myopia incidence or prevalence was observed (P non-linearity = 0.0423; P linearity = 0.442) (Fig. 5). The risk showed a slow decline for SD of less than 8.5 h/day, but the rate of decline increased after 8.5 h/day. However, this effect did not reach statistical significance at all dose levels. Thus, the results of the categorical and continuous dose–response meta-analyses were not entirely consistent, which may be due to differences in the number of studies included and the analytical methods used.

Discussion

This is the first meta-analysis to explore the dose–response relationship between PA,ST,SD and myopia incidence or prevalence in children and adolescents within a 24-h period. The analysis included 45 observational studies, comprising a total of 766,848 children and adolescents. In the continuous dose–response meta-analysis, we found significant linear associations for PA

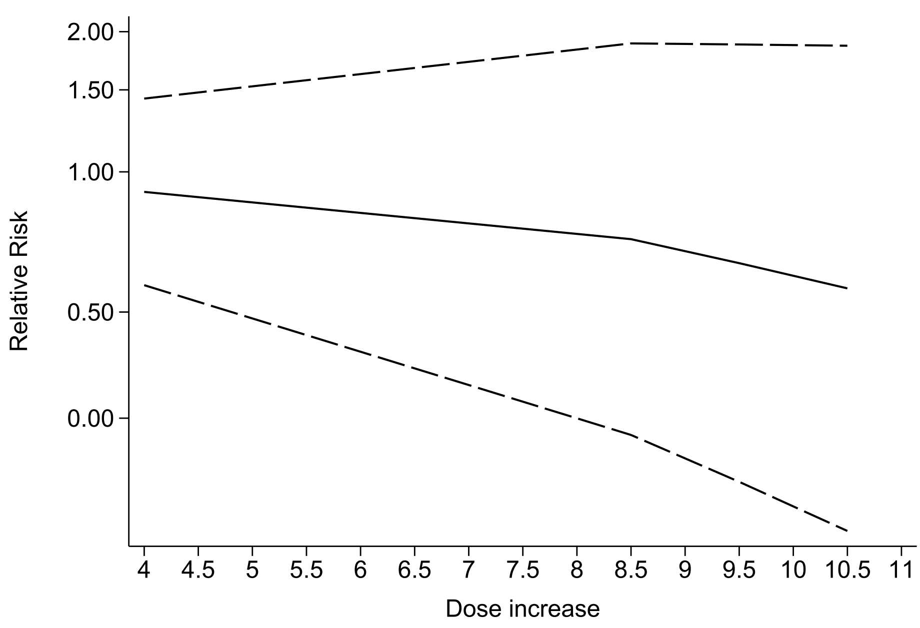

Fig. 5 The continuous dose–response meta-analysis of the association between sleep duration and the risk of metabolic syndrome

and ST, with each additional hour of PA reducing myopia risk by 12% and each additional hour of ST increasing it by 31%. Non-linear relationships were observed for NW and SD, with 1.5 and 2.5 h of NW associated with a 25% and 29% increased risk, respectively. Although longer SD showed a declining trend in myopia risk, the association was not statistically significant. In the categorical dose–response meta-analysis, compared with the lowest category, the highest and intermediate categories of PA (4 h/d and 2 h/d) and SD (10 h/d and 8 h/d) significantly reduced the risk of myopia. In contrast, both the highest category of ST (5 h/d) and NW (7.5 h/d), as well as the intermediate category of ST (3 h/d) and NW (4.5 h/d), significantly increased the risk of myopia.Notably, this meta-analysis revealed substantial heterogeneity ($I^2 > 90\%$ in certain analyses) while exploring the associations between PA, SB, and myopia risk, posing significant challenges to result interpretation. Although subgroup analyses, sensitivity analyses, and multivariable meta-regression (adjusted for age, cycloplegia use, and risk of bias) were implemented to address heterogeneity, fundamental discrepancies in study methodologies continue to raise concerns about the generalizability and robustness of the findings.It is critical to emphasize that the observed dose–response relationships are correlational and do not imply causation. The associations between PA, ST, and myopia risk may be confounded by factors such as outdoor light exposure and educational demands. Non-linear patterns for NW and SD suggest potential threshold effects, where specific exposure levels may differentially influence myopia development. Moderating variables, including population characteristics (e.g., geographic region, ethnicity), behavioral differences (e.g., digital device usage habits), and measurement timing, likely contribute to the complex trends identified. While this study synthesizes critical evidence, the inherent limitations of observational data.

Several subgroup analyses demonstrated robust findings. Overall, the stability and consistency of the pooled estimates were strongly influenced by income level, study design, sample size, prevalence, and myopia definition. Larger studies conducted in high-income countries, focusing on low-prevalence populations and applying the "≤0.5" myopia definition, tended to yield more robust and less variable results. Conversely, smaller samples from low-income countries, high-prevalence subgroups, certain cohort designs, and "other situations" myopia definitions exhibited greater heterogeneity and reduced reliability, particularly when individual studies were excluded.In other words, while some subgroups consistently show strong and stable associations, others are highly sensitive to the exclusion of individual studies, indicating substantial heterogeneity. This highlights the need to interpret the results in the specific conditions of each subgroup and emphasizes that more standardized definitions, larger studies, and careful consideration of socioeconomic and methodological differences are essential to improve the reliability of future studies of myopia risk factors.

The results show that PA is significantly associated with a reduced risk of myopia in children and adolescents. However, the exact mechanisms by which PA prevents myopia remain unclear, though several potential physiological mechanisms have been proposed. First, blood flow to the retina increases rapidly after PA [93], and this improvement in blood circulation may lead to the expansion of the choroidal layer, which could help suppress excessive elongation of the eyeball to some extent [94]. The choroid is an essential vascular structure of the eye, and an increase in choroidal thickness helps maintain the structural stability of the eyeball, preventing excessive axial elongation [95].Recent longitudinal studies, such as the one by Xu et al., have demonstrated that axial elongation is significantly associated with progressive choroidal thinning, a process that plays a crucial role in myopia progression [96]. Second, studies have found that lowering intraocular pressure through medication can slow axial elongation in guinea pigs [97]. A recent Mendelian study also revealed a bidirectional association between myopia and primary open-angle glaucoma mediated by intraocular pressure at the genetic level [98]. Notably, moderate PA has been shown to effectively reduce intraocular pressure [99]. A reduction in intraocular pressure helps alleviate mechanical stress on the eyeball wall, thus reducing the risk of axial elongation and contributing positively to myopia prevention [100]. In conclusion, PA significantly reduces the risk of myopia. These findings highlight the importance of increasing PA levels in myopia prevention and control, but the specific mechanisms still require further investigation to be fully validated.

This study identified a significant association between prolonged SB, including NW and ST, and an elevated risk of myopia in children and adolescents. This association may be attributed to the substantial changes in the overall refractive status of the visual field that occur during extended NW and screen viewing in indoor environments, as opposed to outdoor settings, which may contribute to an increased likelihood of myopia development [4]. A study conducted in Canada found that during near work, myopic children exhibit accommodative demands of 4.69D (video games), 3.68D (reading), and 4.02D (writing) depending on the task [101]. Previous studies have shown that accommodative lag increases significantly with higher accommodative demands, sometimes exceeding the static accommodative baseline of 1 to 1.5 diopters [102]. This results in hyperopic defocus in the peripheral retina, which stimulates axial elongation and contributes to the development of myopia [96]. To mitigate the issue of bidirectional causality (i.e., lower PA potentially resulting from myopia, which in turn leads to increased ST), Liu et al. conducted a bidirectional Mendelian randomization analysis. Their findings revealed no significant effect of myopia on PA or ST, suggesting that myopia does not directly lead to reduced PA or increased ST in children. [103]

Additionally, prolonged SB and lack of PA are risk factors for overweight and obesity [104, 105]. Previous research has explored the relationship between obesity and myopia. A cross-sectional study in Korea investigated the impact of obesity on the prevalence of myopia in children and adolescents, revealing that obesity is associated with high myopia but not with mild or moderate myopia [106]. Similarly, a cross-sectional study of 1.3 million Israeli adolescents showed that both low BMI and high BMI were significantly associated with mild, moderate, and severe myopia compared to normal BMI [107]. A prospective cohort study by Jin-Liu-Xing et al. examined the moderating effect of outdoor activity time on the relationship between overweight and myopia in children, finding that children with more outdoor activity had a lower risk of myopia. As outdoor activity time decreased, overweight children were more likely to develop myopia than children with normal weight [108]. Therefore, appropriately managing children and adolescents' daily activities, increasing PA, and reducing prolonged SB are effective strategies for preventing myopia.

Our categorical dose–response meta-analysis suggests that longer SD may help reduce the risk of myopia development in children and adolescents; however, no specific dose level reached statistical significance in the continuous dose–response analysis. This discrepancy could stem from the limited number of studies included in the continuous analysis, as well as variations in study design, population characteristics, and measurement methods (e.g., self-reported vs. objective measures of sleep). Therefore, further large-scale and well-designed studies are required to confirm the dose–response relationship between sleep duration and myopia risk.Previous studies have found that shorter SD is associated with an increased risk of myopia, with SD less than 7 h increasing the likelihood of myopia development [109, 110]. However, some researchers have drawn opposite conclusions [111]. It is noteworthy that the reduction in SD among children and adolescents may be related to academic pressure, which increases the opportunity for engaging in NW under artificial light at night. Such exposure can suppress melatonin secretion and disrupt circadian rhythms, potentially contributing to the onset and progression of myopia. Ranjay Chakraborty et al. discovered that, compared to emmetropic children, the secretion of melatonin in myopic children is delayed by 1 h and 8 minutes [112]. In myopic adults, the delay is even longer, extending to 1 h and 12 minutes [113].Furthermore, there is a significant reduction in nocturnal melatonin secretion in myopic patients, and this reduction is linearly correlated with the severity of myopia. Animal experiments have also been conducted to validate this perspective. In chickens, when chickens are exposed to a constant light environment (i.e., when circadian rhythms are disrupted), the axial length of the eye extends rapidly both during the day and at night, leading to the development of myopia or hyperopia [114]. These studies suggest that circadian rhythms may play a key role in ocular growth. The disruption of circadian rhythms may interfere with normal melatonin secretion, leading to abnormal ocular growth. In CBA/CaJ mice (a strain capable of melatonin secretion), form-deprived eyes exhibited myopic refractive changes accompanied by alterations in retinal dopamine levels. This finding suggests that melatonin-mediated changes in retinal dopamine levels play a role in the development of myopia [115]. However, the mechanisms by which SD affects the development of myopia in adolescents and children are not yet clear. Future research should focus on elucidating the gene-environment interactions between circadian rhythm disorders and the development of myopia, and make use of advancements in chronobiology and genomics for in-depth exploration.

Strengths and limitations

This study is the first to conduct a dose–response meta-analysis evaluating the association between PA, SB, SD, and the incidence or prevalence of myopia in children and adolescents. Both categorical and continuous dose–response meta-analyses were used to examine the linear or nonlinear relationship between daily PA and myopia incidence or prevalence, quantifying the specific threshold of daily PA that may contribute to the onset or prevalence of myopia. Strict criteria were applied, requiring refractive error to be measured by an ophthalmologist or optometrist, excluding studies with self-reported myopia. The review adhered to the MOOSE guidelines for meta-analyses of observational studies, ensuring rigorous scientific standards in identifying and evaluating relevant literature. Finally, Despite the high heterogeneity, our study employed rigorous methodological approaches to address these variations. Subgroup analyses, sensitivity analyses, and multivariable meta-regression (adjusted for factors such as age, cycloplegia use, and risk of bias) were conducted to explore and mitigate the impact of these differences.

At the same time, the limitations of this study must be acknowledged. First, most included studies did not stratify participants by sex, which limits our ability to compare results between males and females. In addition, data on individual-level confounders were incomplete, for example, genetic susceptibility to myopia and UV exposure during outdoor activities, so we were unable to conduct subgroup analyses to assess their specific effects on myopia risk. Future studies should aim to collect more comprehensive data on these variables to better understand their roles in the development of myopia. Second, only one of the 45 studies objectively measured children's PA and SB using accelerometers; the remaining studies relied on self-reported or parent-reported questionnaires. This reliance on subjective measures may introduce recall bias and underestimation of total activity, potentially diluting or inflating observed associations. Future studies would benefit from incorporating objective measures—such as accelerometers, wearable devices, or digital logs—to enhance accuracy and reliability. Third, due to the limited number of studies, both cross-sectional and non-cycloplegic studies were included, potentially overestimating myopia incidence and contributing to greater heterogeneity and uncertainty in the results. Future research should adopt more rigorous methodologies—such as using cycloplegic refraction protocols in longitudinal or cohort designs—to improve diagnostic accuracy and reduce methodological bias. Fourth, assumptions and simplifications were made when classifying PA into lowest, intermediate, and highest categories, which could have introduced some degree of misclassification. Finally, High heterogeneity ($I^2 > 90\%$ in some analyses) underscores significant variations in study designs, sample populations, and measurement techniques among the included studies. Future research should prioritize standardized study designs and measurement approaches to enable more reliable evaluations of the relationships between these factors and myopia risk in children and adolescents.

Conclusion

This systematic review and meta-analysis indicate a linear association between PA, ST, SD and the incidence or prevalence of myopia, while NW and SD exhibit a nonlinear relationship with myopia incidence or prevalence. Increased PA is associated with a reduced risk of myopia, whereas prolonged ST and NW are linked to an elevated risk. However, the relationship between SD and myopia remains inconclusive, necessitating further research to clarify the association between SD and myopia.

Abbreviations

PA	Physical activity
SB	Sedentary behavior
SD	Sleep duration
ST	Screen time
NW	Near work
D	Diopter
OR	Odd ratio
CI	Confidence interval
JBI	Joanna Briggs Institute

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-22434-8.

Supplementary Material 1.

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Authors' contributions
DHM:Conceptualization,Methodology,Formal analysis,Investigation,Data curation, Writing—original draft preparation,Visualization. JLQ:Methodology, Formal analysis,Investigation,Data curation,Writing—review and editing. LXQ:Writing—Conceptualization,original draft preparation. YCY:Writing—original draft preparation,Data curation. TBW:Conceptualization,Writing—review and editing,Supervision,Project administration. All authors have read and agreed to the published version of the manuscript.

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Data availability
The full dataset and supplementary information used in this study are publicly available at Mendeley Data [Ding, Huimin; Chun, Joseph*; Jiang, LiQun; Lin, XuanQiao; Ye, ChaoYing (2024), 'Association of Physical Activity, Sedentary Behaviour, Sleep Duration, and Myopia in Children and Adolescents: A Systematic Review and Dose-Response Meta-Analysis', Mendeley Data, V1, Doi: 10.17632/fkc4r27xp4.1].

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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