

Preplanned Studies

Network Analysis of Visual Behaviors, Family Factors, and Refractive Status in Chinese Schoolchildren — 10 PLADs, China, 2020–2024

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Summary

What is already known about this topic?

Myopia is a growing public health concern, with established risk factors including near-work activities and family-related factors. However, the interactions between visual behaviors and family factors remain poorly understood.

What is added by this report?

This study uses network analysis to examine the relationships among visual behaviors, family factors, and refractive status in 29,525 children. It identifies key central and bridging nodes, highlighting the need for age-specific interventions.

What are the implications for public health practice?

Targeting postural behaviors, reducing screen time, and promoting family-based interventions may help prevent myopia.

children than among older children (0.76 *vs.* 0.67), whereas older children exhibited fewer but stronger connections. Based on cycloplegic refraction in the study sample, the detection rate of myopia was also higher among older children than among younger children [51.85% (4,395/8,477) *vs.* 15.64% (3,291/21,048)].

Conclusion: This study provides a comprehensive understanding of the interrelationships among visual behaviors, family factors, and refractive status, highlighting postural behaviors and the bridging roles of screen time, homework/reading, and tutoring activities. Age-related differences in network characteristics may help inform future prevention strategies.

ABSTRACT

Introduction: Myopia is a growing public health concern, particularly in East Asia, where it contributes substantially to pediatric healthcare expenditures. The development of myopia is influenced by complex interactions between visual behaviors, family factors, and refractive status.

Methods: This study used network analysis to examine the interrelationships among visual behaviors, family factors, and refractive status in 29,525 Chinese schoolchildren aged 6–14 years. Central and bridging nodes were identified within the myopia development network.

Results: Postural behaviors dominated the network, with eye-to-book distance (strength=1.20) and head support (1.16) emerging as the most central nodes. In contrast, break location (bridge=0.30) was the strongest behavioral bridge node, followed by non-study screen time (0.24) and homework/reading time (0.22). Network density was higher among younger

The high prevalence of myopia and its irreversible ocular complications underscore the urgency of early prevention and control strategies. In China, the annual economic burden of myopia in urban areas was estimated at 173.6 billion Chinese Yuan (CNY) [approximately 26.3 billion United States dollars (USD)], with rapid urbanization and increasing educational pressure identified as key drivers of this growing burden (1). Myopia develops through complex interactions between genetic predisposition and environmental influences, including lifestyle and behavioral exposures (2). Whereas traditional studies typically focus on isolated risk factors, network analysis provides a complementary approach by modeling interrelationships and identifying central nodes (highly influential factors) and bridging nodes (connectors between domains). In contrast to conventional regression models that estimate independent associations, network analysis enables simultaneous examination of interconnections among behavioral, family, and physiological factors, making it well suited to the multifactorial nature of myopia. Accordingly, this study applies network analysis to examine the

interrelationships among visual behaviors, family factors, and refractive status in Chinese schoolchildren, with the aims of identifying central and bridging factors, comparing network structures across age groups, and informing targeted prevention strategies.

This study analyzed data from a national cross-sectional survey on eye development and related behavioral factors among children and adolescents conducted by the Chinese Center for Disease Control and Prevention between 2020 and 2024. The selected provincial-level administrative divisions (Beijing, Shanxi, Liaoning, Zhejiang, Shandong, Henan, Hunan, Guangdong, Chongqing, and Shaanxi) represent eastern, central, and western China and encompass varying levels of economic development and urbanization. A multistage cluster sampling design was used to recruit students from kindergarten to high school, with an initial sample of 48,646 participants. Although the original survey included a broad age range, the present analysis was restricted to children aged 6–14 years. Exclusions comprised participants outside this age range ($n=1,947$); missing or abnormal axial length values (10–40 mm) ($n=662$); missing spherical equivalent data (669); abnormal spherical equivalent values outside $Q1 - 3 \times \text{interquartile range (IQR)}$ or $Q3 + 3 \times \text{IQR}$ ($n=1,144$); missing or invalid screen time data ($n=8,244$); missing parental myopia data ($n=947$); and invalid responses for daily outdoor activity time ($n=3,901$), homework/reading time ($n=709$), tutoring duration ($n=881$), break-related variables ($n=14$), and posture variables ($n=3$). The final analytic sample comprised 29,525 children aged 6–14 years.

All participants underwent standardized ophthalmic examinations following a unified protocol. Noncycloplegic and cycloplegic autorefractor were performed using identical autorefractor models across all sites. Cycloplegia was induced using 0.5% tropicamide administered four times at 5-minute intervals. Due to high inter-eye correlation, only right-eye data were analyzed. Spherical equivalent (SE) was calculated as sphere plus half cylinder. Myopia was defined as cycloplegic SE ≤ -0.50 diopters (D), and insufficient hyperopic reserve as age-specific cycloplegic SE below established normative thresholds (3). Visual behaviors were assessed using standardized questionnaires, including daily outdoor activity time, homework/reading time, tutoring duration, non-study screen time, break location and frequency, and six posture-related items during reading and writing (chest-to-desk distance, eye-to-book distance, finger-

to-pen distance, lying posture, head support, and sitting posture). Parental myopia and covariates (age, sex, province, residence, and parental education) were also collected.

Continuous variables are presented as mean $\pm$ standard deviation and compared using the Wilcoxon rank-sum test. Categorical variables are presented as frequencies (percentages) and compared using Pearson's chi-square test. All tests were two-sided, with statistical significance set at $P < 0.05$. Networks were estimated using EBICglasso (Extended Bayesian Information Criterion graphical Least Absolute Shrinkage and Selection Operator) with LASSO (Least Absolute Shrinkage and Selection Operator) regularization. Edge weights represent partial correlations between nodes, density reflects the proportion of observed connections, strength centrality is the sum of absolute edge weights, and bridge centrality quantifies cross-module connectivity. To reduce confounding, each node was residualized for prespecified covariates (age, sex, province, residence, and parental education) prior to network estimation. These variables were selected based on prior evidence as established confounders of the visual behavior–myopia associations. To account for clustering at the school level, cluster-robust standard errors were applied, and province fixed effects were included. Stability was evaluated using 1,000 bootstrap resamples, with a correlation stability (CS) coefficient > 0.50 indicating acceptable reliability. Participants were stratified into younger (6–9 years) and older (10–14 years) groups to examine developmental differences while maintaining network stability estimation. The Network Comparison Test (NCT) assessed differences in global structure and edge weights between groups. All analyses were performed in R software (version 4.5.2; R Foundation for Statistical Computing, Vienna, Austria) using the q graph, bootnet, and NCT packages.

A total of 29,525 children were included, of whom 21,048 [71.29% (21,048/29,525)] were aged 6–9 years and 8,477 [28.71% (8,477/29,525)] were aged 10–14 years. Compared with younger children, older children had lower spherical equivalent (0.46 ± 1.10 D *vs.* -0.81 ± 1.63 D, $P < 0.001$) and higher axial length-to-corneal radius ratio (2.96 ± 0.09 *vs.* 3.06 ± 0.11 , $P < 0.001$). Based on cycloplegic refraction in our study sample, the detection rate of myopia was substantially higher in older children [51.85% (4,395/8,477) *vs.* 15.64% (3,291/21,048), $P < 0.001$]. Significant differences were also observed in residence, parental

TABLE 1. Characteristics of study participants.

Characteristic	Total (N=29,525)	6–9 years (n=21,048)	10–14 years (n=8,477)	P
Age, years, mean±SD	8.66±1.87	7.66±0.87	11.17±1.21	<0.001
Sex, n (%)				0.178
Male	15,127 (51.23)	10,731 (50.98)	4,396 (51.86)	
Female	14,398 (48.77)	10,317 (49.02)	4,081 (48.14)	
Residence, n (%)				<0.001
Urban	22,270 (75.43)	15,544 (73.85)	6,726 (79.34)	
Rural	7,255 (24.57)	5,504 (26.15)	1,751 (20.66)	
Parental education, n (%)				<0.001
≤ High school	12,447 (42.16)	8,274 (39.31)	4,173 (49.23)	
Associate/Bachelor's degree	15,769 (53.41)	11,742 (55.79)	4,027 (47.51)	
Graduate degree	1,208 (4.09)	945 (4.49)	263 (3.10)	
Parental myopia, n (%)				<0.001
Neither parent myopic	4,513 (15.29)	3,289 (15.63)	1,224 (14.44)	
One parent myopic	12,634 (42.79)	9,541 (45.33)	3,093 (36.49)	
Both parents myopic	12,378 (41.92)	8,218 (39.04)	4,160 (49.07)	
AL/CR ratio, mean±SD	2.99±0.11	2.96±0.09	3.06±0.11	<0.001
Spherical equivalent, D, mean±SD	0.10±1.40	0.46±1.10	−0.81±1.63	<0.001
Myopia, n (%)	7,686 (26.03)	3,291 (15.64)	4,395 (51.85)	<0.001
Pre-myopia, n (%)	12,284 (41.61)	9,291 (44.14)	2,993 (35.31)	<0.001
Emmetropia, n (%)	9,555 (32.36)	8,466 (40.22)	1,089 (12.85)	<0.001

Abbreviation: AL/CR ratio=axial length-to-corneal radius ratio; D=Diopters; SD=standard deviation; SE=spherical equivalent.

TABLE 2. Network structure metrics.

Network	Nodes	Edges	Density	Strength
Full sample	15	80	0.76	5.55
Age 6–9 years	15	80	0.76	4.64
Age 10–14 years	15	71	0.67	4.74

Note: Density=proportion of possible edges present; Strength=sum of absolute edge weights. Network Comparison Test showed no significant difference in global structure between age groups ($P=0.802$), although edge weights differed ($P=0.010$).

education, and parental myopia (all $P<0.001$) (Table 1). Distributions of behavioral variables are presented in Supplementary Table S1 (available at <https://weekly.chinacdc.cn/>).

The full-sample network included 15 nodes and 80 edges, with a density of 0.76 and mean strength of 5.55 (Table 2, Figure 1A). Behavioral variables were densely interconnected, particularly within near-work activities (homework/reading time, tutoring duration, and non-study screen time). Posture variables formed a distinct cluster, with eye-to-book distance and head support showing strong links to physiological outcomes. Age-stratified analysis revealed differences in network characteristics (Table 2, Figure 1B–C). The younger group showed higher density (0.76 *vs.* 0.67), whereas the older group showed slightly greater overall

strength (4.74 *vs.* 4.64). However, the NCT indicated no significant difference in global structure between groups ($P=0.802$), although specific edge weights differed ($P=0.010$). Bootstrap analysis supported network stability, with a CS coefficient of 0.75 for strength centrality and generally narrow confidence intervals for edge estimates.

Strength centrality indicated that posture-related nodes dominated the network. Eye-to-book distance (1.20) and head support (1.16) were the most central nodes, followed by lying posture (0.97) and chest-to-desk distance (0.92) (Figure 2A, Supplementary Table S2, available at <https://weekly.chinacdc.cn/>). Among behavioral variables, break location ranked fifth (0.89). In contrast, non-study screen time (0.42), tutoring duration (0.44), homework/reading time

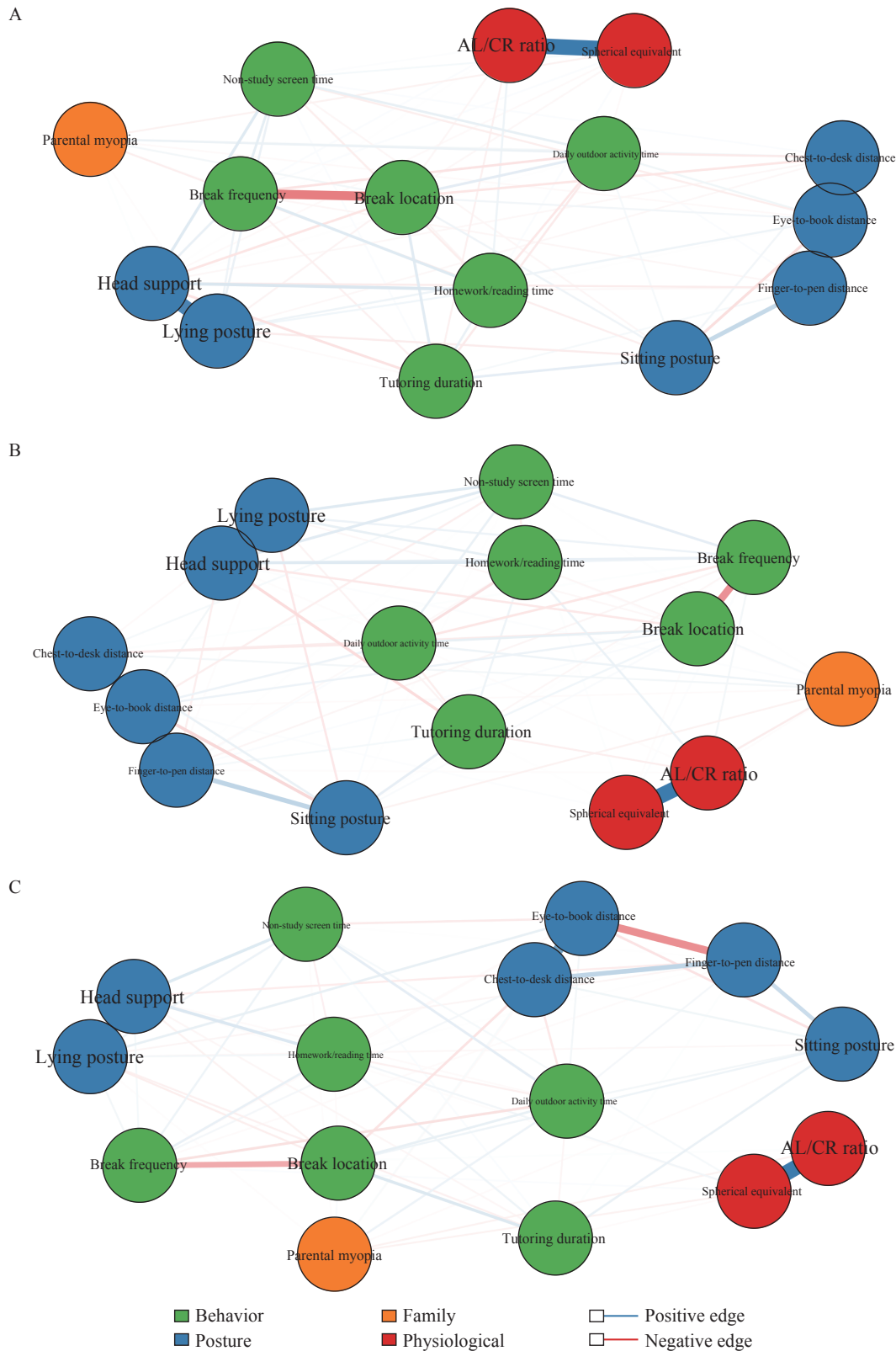


FIGURE 1. Network structures of the full sample and age-stratified groups. Networks for (A) full sample ($N=29,525$), (B) children aged 6–9 years ($n=21,048$), and (C) children aged 10–14 years ($n=8,477$). Nodes are colored by type: green=Behavior (6 nodes), blue=Posture (6 nodes), orange=Family (1 node), red=Physiological (2 nodes). Edges represent partial correlations: blue=positive, red=negative. Edge thickness indicates correlation strength. Abbreviation: AL/CR ratio=axiallength-to-corneal radius ratio.

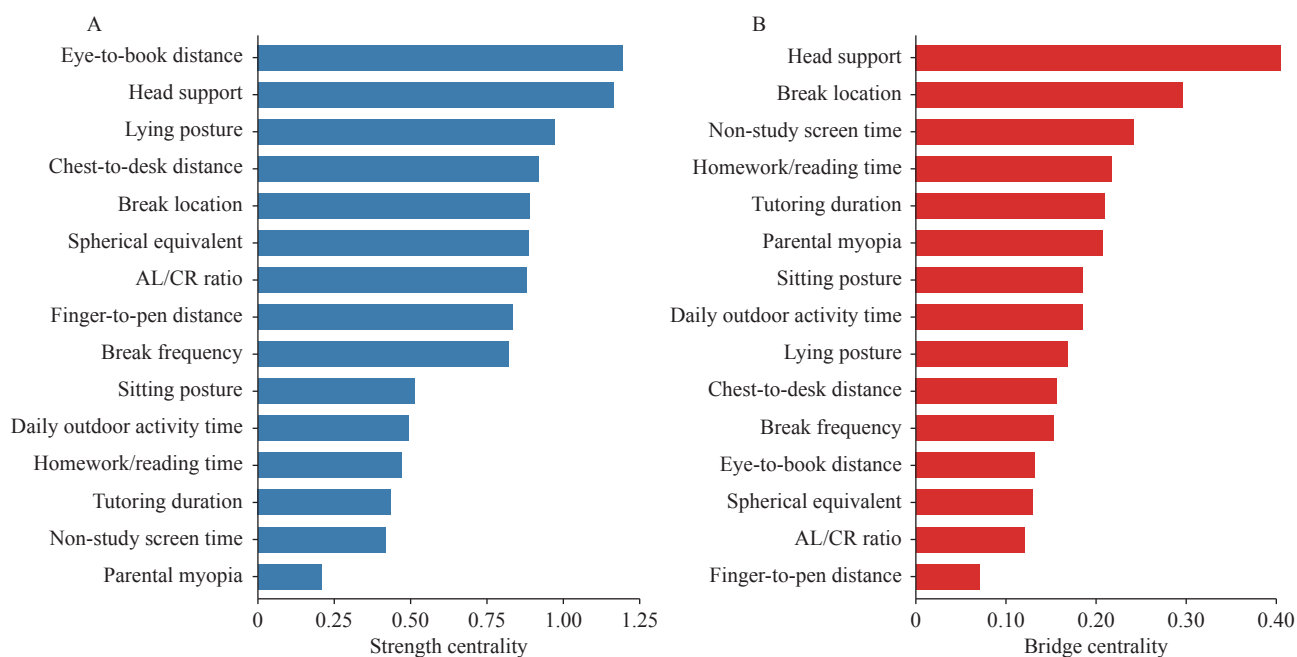


FIGURE 2. Node centrality analysis. (A) Strength centrality rankings (15 nodes). (B) Bridge centrality rankings (15 nodes). Note: In panel A, higher strength indicates greater influence in the network. Nodes are arranged in descending order of strength. In panel B, higher bridge strength indicates greater importance in connecting different modules (Behavior, Posture, Family Factors, Physiological). Error bars represent 95% bootstrap confidence intervals. Abbreviation: AL/CR ratio=axiallength-to-corneal radius ratio.

(0.47), and outdoor time (0.50) showed low centrality, while parental myopia (0.21) exhibited the lowest value. Bridge centrality identified key connectors between modules (Figure 2B, Supplementary Table S3, available at <https://weekly.chinacdc.cn/>). Head support (0.41) was the strongest bridge node linking posture and physiological domains, followed by break location (0.30). Non-study screen time (0.24), homework/reading time (0.22), and tutoring duration (0.21) also showed moderate bridging roles. Parental myopia (0.21) additionally demonstrated cross-module connectivity, suggesting a potential role of family factors within the broader network structure.

DISCUSSION

This study applied network analysis to examine the interrelationships among visual behaviors, family factors, and refractive status in Chinese schoolchildren. In contrast to traditional approaches focusing on isolated risk factors, the findings highlight a structured interdependence among behavioral, familial, and physiological domains, offering a systems-level perspective on myopia development.

Postural behaviors, particularly eye-to-book distance and head support, occupied central positions in the

network, indicating stronger connectivity with other variables than most behavioral and familial factors. Their centrality underscores their relevance within the broader behavioral–physiological system and supports further longitudinal investigation. These findings align with previous evidence linking near-work posture to retinal defocus, ocular responses, and myopia-related structural changes (4).

Screen time and homework, although less central, functioned as key bridging nodes connecting behavioral and physiological domains. This suggests that near-work activities may exert influence through contextual pathways involving posture and refractive outcomes, consistent with prior research (5–6). The results emphasize the importance of considering both duration and context of near-work behaviors in prevention strategies.

Parental myopia emerged as a bridging factor between family and behavioral domains, consistent with established evidence of familial aggregation in childhood myopia (7). Its cross-domain connectivity suggests that family-related factors may interact with behavioral patterns within the broader network, although causal direction cannot be inferred from the cross-sectional data (8).

Age-stratified analyses revealed broadly similar

network structures but differences in specific connections. Younger children showed more densely interconnected behavioral and postural relationships, whereas older children exhibited more selective connectivity. These findings suggest developmental variation in the relative importance of specific pathways, supporting the potential value of age-tailored prevention strategies.

A key strength of this study is the application of network analysis to capture interdependencies among multiple risk domains. This approach moves beyond isolated associations by identifying central and bridging nodes, offering a structured view of myopia-related factors (9). The observed age-related differences further support a dynamic, developmentally sensitive framework for understanding myopia risk.

Several limitations should be noted. First, the cross-sectional design precludes causal inference. Second, residual confounding from unmeasured factors (e.g., household income, school policies, light exposure) may remain. Third, behavioral measures were self-reported and subject to recall bias. Fourth, findings are limited to children aged 6–14 years. Fifth, although missing data led to exclusions, comparisons suggested limited selection bias. Future studies should include broader age ranges and longitudinal designs to strengthen generalizability and causal interpretation.

In conclusion, network analysis revealed that posture-related behaviors occupy central positions in the myopia-related system, while screen time, homework, and parental myopia function as key bridging factors. Age-related variations in network structure further suggest developmental differences in the organization of myopia risk. These findings provide a systems-level perspective that may inform future prevention strategies.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Distribution of visual behavioral variables by age group.

Variable	Category	Total (N=29,525)	Aged 6–9 years (n=21,048)	Aged 10–14 years (n=8,477)
Daily outdoor activity time (hours/day)				
	<1	5,828 (19.74)	3,964 (18.83)	1,864 (21.99)
	1–2	11,444 (38.76)	8,193 (38.93)	3,251 (38.35)
	2–3	5,901 (19.99)	4,239 (20.14)	1,662 (19.61)
	≥3	6,352 (21.51)	4,652 (22.10)	1,700 (20.05)
Homework/reading time (hours/day)				
	No homework	1,091 (3.70)	940 (4.47)	151 (1.78)
	<1	8,557 (28.98)	6,612 (31.41)	1,945 (22.94)
	1–2	12,312 (41.70)	8,834 (41.97)	3,478 (41.03)
	2–3	5,135 (17.39)	3,233 (15.36)	1,902 (22.44)
	≥3	2,430 (8.23)	1,429 (6.79)	1,001 (11.81)
Tutoring duration (hours/week)				
	None	14,187 (48.05)	10,936 (51.96)	3,251 (38.35)
	<1	3,079 (10.43)	2,368 (11.25)	711 (8.39)
	1–2	6,231 (21.10)	4,249 (20.19)	1,982 (23.38)
	2–3	3,186 (10.79)	1,939 (9.21)	1,247 (14.71)
	≥3	2,842 (9.63)	1,556 (7.39)	1,286 (15.17)
Non-study screen time (hours/day)				
	None	5,908 (20.01)	4,591 (21.81)	1,317 (15.54)
	<0.5	11,285 (38.22)	8,155 (38.74)	3,130 (36.92)
	0.5–1	6,874 (23.28)	4,687 (22.27)	2,187 (25.80)
	1–2	3,876 (13.13)	2,635 (12.52)	1,241 (14.64)
	2–3	939 (3.18)	604 (2.87)	335 (3.95)
	≥3	643 (2.18)	376 (1.79)	267 (3.15)
Break location				
	Indoor	17,082 (57.86)	11,997 (57.00)	5,085 (59.99)
	Outdoor	12,443 (42.14)	9,051 (43.00)	3,392 (40.01)
Break frequency (outdoor)				
	Every break	16,306 (55.23)	11,876 (56.42)	4,430 (52.26)
	Every 2 breaks	8,252 (27.95)	5,690 (27.03)	2,562 (30.22)
	Rarely	4,400 (14.90)	3,089 (14.68)	1,311 (15.47)
	Never	567 (1.92)	393 (1.87)	174 (2.05)
Chest-to-desk distance				
	Never	2,283 (7.73)	1,545 (7.34)	738 (8.71)
	Occasionally	15,381 (52.09)	11,231 (53.36)	4,150 (48.96)
	Often	8,477 (28.71)	6,006 (28.53)	2,471 (29.15)
	Always	3,384 (11.46)	2,266 (10.77)	1,118 (13.19)
Eye-to-book distance				
	Never	2,079 (7.04)	1,465 (6.96)	614 (7.24)
	Occasionally	15,507 (52.52)	11,148 (52.96)	4,359 (51.42)
	Often	9,012 (30.52)	6,511 (30.93)	2,501 (29.50)
	Always	2,927 (9.91)	1,924 (9.14)	1,003 (11.83)

Continued

Variable	Category	Total (N=29,525)	Aged 6–9 years (n=21,048)	Aged 10–14 years (n=8,477)
Finger-to-pen distance	Never	2,268 (7.68)	1,504 (7.15)	764 (9.01)
	Occasionally	12,422 (42.07)	8,962 (42.58)	3,460 (40.82)
	Often	10,206 (34.57)	7,475 (35.51)	2,731 (32.22)
	Always	4,629 (15.68)	3,107 (14.76)	1,522 (17.95)
Lying posture	Never	14,010 (47.45)	10,181 (48.37)	3,829 (45.17)
	Occasionally	12,237 (41.45)	8,644 (41.07)	3,593 (42.39)
	Often	2,731 (9.25)	1,852 (8.80)	879 (10.37)
	Always	547 (1.85)	371 (1.76)	176 (2.08)
Head support	Never	15,590 (52.80)	11,593 (55.08)	3,997 (47.15)
	Occasionally	11,382 (38.55)	7,775 (36.94)	3,607 (42.55)
	Often	2,201 (7.45)	1,434 (6.81)	767 (9.05)
	Always	352 (1.19)	246 (1.17)	106 (1.25)
Sitting posture	Never	3,915 (13.26)	2,791 (13.26)	1,124 (13.26)
	Occasionally	10,337 (35.01)	7,417 (35.24)	2,920 (34.45)
	Often	10,266 (34.77)	7,413 (35.22)	2,853 (33.66)
	Always	5,007 (16.96)	3,427 (16.28)	1,580 (18.64)

Note: Data are presented as *n* (%). The percentages may not sum to 100 because of rounding.

SUPPLEMENTARY TABLE S2. Strength centrality rankings.

Rank	Node name	Node type	Strength
1	Eye-to-book distance	Posture	1.20
2	Head support	Posture	1.16
3	Lying posture	Posture	0.97
4	Chest-to-desk distance	Posture	0.92
5	Break location	Behavior	0.89
6	Spherical equivalent	Physiological	0.89
7	AL/CR ratio	Physiological	0.88
8	Finger-to-pen distance	Posture	0.83
9	Break frequency	Behavior	0.82
10	Sitting posture	Posture	0.51
11	Daily outdoor activity time	Behavior	0.50
12	Homework/reading time	Behavior	0.47
13	Tutoring duration	Behavior	0.44
14	Non-study screen time	Behavior	0.42
15	Parental myopia	Family	0.21

Note: Strength centrality indicates the sum of absolute edge weights connected to each node. Higher values denote greater influence in the network.

Abbreviation: AL/CR ratio=axial length-to-corneal radius ratio.

SUPPLEMENTARY TABLE S3. Bridge centrality rankings.

Rank	Node name	Node type	Bridge strength	Connected modules
1	Head support	Posture	0.41	Posture ↔ Physiological
2	Break location	Behavior	0.30	Behavior ↔ Physiological
3	Non-study screen time	Behavior	0.24	Behavior ↔ Physiological
4	Homework/reading time	Behavior	0.22	Behavior ↔ Physiological
5	Tutoring duration	Behavior	0.21	Behavior ↔ Physiological
6	Parental myopia	Family	0.21	Family ↔ Others
7	Sitting posture	Posture	0.19	Posture ↔ Physiological
8	Daily outdoor activity time	Behavior	0.19	Behavior ↔ Physiological
9	Lying posture	Posture	0.17	Posture ↔ Physiological
10	Chest-to-desk distance	Posture	0.16	Posture ↔ Physiological
11	Break frequency	Behavior	0.15	Behavior ↔ Physiological
12	Eye-to-book distance	Posture	0.13	Posture ↔ Physiological
13	Spherical equivalent	Physiological	0.13	Physiological ↔ Behavior/Posture
14	AL/CR ratio	Physiological	0.12	Physiological ↔ Behavior/Posture
15	Finger-to-pen distance	Posture	0.07	Posture ↔ Physiological

Note: Bridge centrality quantifies the sum of absolute edge weights connecting a given node to nodes in other modules. Higher values indicate stronger cross-module connectivity

Abbreviation:AL/CR ratio=axial length-to-corneal radius ratio.