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Prevalence and Associated Factors of Symptomatic Dry Eye Disease Among Secondary School Students in Heping District, Tianjin, China

Lu Tian
Tianjin Eye Hospital
Xiaoyan Yang
Tianjin Eye Hospital
Jinrong Zhao
Tianjin Eye Hospital
Yanglin Jiang
Tianjin Eye Hospital
Xin Chen
Tianjin Eye Hospital
Zhiyan Ji
Tianjin Eye Hospital
Xinyu Yang
Tianjin Eye Hospital
Bochen Gao
Tianjin Eye Hospital
Changqi Li
Tianjin Eye Hospital
Lihua Li
Tianjin Eye Hospital
Quanhong Han
hanquanhong126@126.com

Tianjin Eye Hospital

Article

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Abstract

Dry eye disease (DED) is increasingly recognized in younger populations, yet epidemiological evidence in adolescents remains limited. This school-based cross-sectional study investigated the prevalence of symptomatic DED and its associated factors among secondary school students in Heping District, Tianjin, China. Dry eye symptoms were assessed using the Ocular Surface Disease Index (OSDI), and symptomatic DED was defined as an OSDI score ≥13. Visual discomfort related to near work was evaluated using the Convergence Insufficiency Symptom Survey (CISS). Generalized estimating equation (GEE) logistic regression analyses were performed to identify factors associated with symptomatic DED. Among 2,091 participants, the prevalence of symptomatic DED was 15.4%. In the primary multivariable GEE model, history of allergic rhinitis/conjunctivitis, history of hordeolum/chalazion, middle school stage, screen time >2 h/day, outdoor activity ≤2 h/day, and sleep duration <6 h/day were independently associated with symptomatic DED. In the sensitivity analysis additionally adjusting for CISS, allergic history, middle school stage, and increased screen time remained significant. Symptomatic DED was common in this population and was consistently associated with allergic conditions and increased screen exposure.

Introduction

Dry eye disease (DED) is a multifactorial disorder of the ocular surface characterized by ocular discomfort, visual disturbance, and tear film instability that may result in potential ocular surface damage. According to the TFOS DEWS II Definition and Classification Report, DED is defined as a disease characterized by a loss of homeostasis of the tear film accompanied by ocular symptoms, in which tear film instability, hyperosmolarity, ocular surface inflammation, and neurosensory abnormalities play etiological roles [1]. Due to its chronic nature and its adverse effect on visual function, daily activities, and quality of life, DED has emerged as a significant global public health concern. The TFOS DEWS II Epidemiology Report indicated that the prevalence of DED varies widely across different populations, ranging from approximately 5% to 50%, depending on geographic location, diagnostic criteria, and study design [2]. In China, a large systematic review and meta-analysis revealed considerable regional variations in the prevalence of DED and highlighted the influence of demographic and geographic factors on disease distribution [3].

Although DED has traditionally been considered more common among middle-aged and older adults, dry eye symptoms and DED have also been reported in younger populations [4,5]. Several studies have documented ocular discomfort and dry eye-related symptoms among adolescents and school-aged children, particularly in association with prolonged digital device use [6,7]. In recent years, rapid technological development has significantly changed the lifestyle and learning habits of adolescents. The widespread use of smartphones, tablets, and computers for educational and recreational purposes has led to prolonged digital screen exposure among students. Prolonged digital device use may reduce blink frequency, increase incomplete blinking, and accelerate tear film evaporation, thereby contributing

to ocular surface discomfort and dry eye symptoms [8]. Consistent with these physiological mechanisms, epidemiological studies have reported that excessive digital screen exposure is associated with a higher likelihood of dry eye symptoms among young populations. For example, Mohan et al. [7] reported a high prevalence of digital eye strain and dry eye-related symptoms among students engaged in prolonged online learning during the COVID-19 pandemic. In addition to digital screen exposure, other lifestyle-related factors, including insufficient sleep and environmental challenges associated with modern lifestyles, may also influence ocular surface health and contribute to the development of dry eye symptoms [9,10]. Moreover, allergic conditions such as allergic conjunctivitis may induce ocular surface inflammation and tear film instability, potentially contributing to dry eye symptoms among younger individuals [11].

Large-scale epidemiological studies commonly rely on validated symptom questionnaires to assess dry eye symptoms in community-based populations. The Ocular Surface Disease Index (OSDI) is one of the most widely used instruments for evaluating dry eye symptoms and their impact on vision-related quality of life [12]. The TFOS DEWS II Epidemiology Report noted that symptom-based questionnaires, including instruments such as the OSDI, are commonly used in epidemiological surveys to estimate symptomatic DED [2]. Although dry eye symptoms in younger populations have received increasing attention, existing evidence remains heterogeneous, and data on associated factors in specific urban adolescent populations in China are still limited. As a large urban district in northern China, Tianjin provides a relevant setting for examining dry eye symptoms in adolescents exposed to contemporary educational and screen-based lifestyles. In addition, the relationship between binocular vision–related symptoms and dry eye symptoms in adolescents remains insufficiently characterized. Therefore, this study aimed to investigate the prevalence of symptomatic DED and its associated factors among secondary school students in Heping District, Tianjin. Using a school-based cross-sectional design and the OSDI questionnaire, this study assessed dry eye symptoms and analyzed demographic, behavioral, and clinical factors associated with symptomatic DED. The findings may provide epidemiological evidence for the prevention and early management of dry eye symptoms among secondary school students.

Methods

Study design and participants

This school-based cross-sectional study was conducted among secondary school students in Heping District, Tianjin, China, between October and December 2025. The sample size was estimated using a standard formula for cross-sectional studies. Assuming a prevalence of symptomatic DED of 15%, a 95% confidence level (Z = 1.96), and a margin of error of 2%, the minimum required sample size was calculated to be approximately 1,225 participants. To allow for non-response and invalid questionnaires, a larger target sample size was used. A total of 2,250 students were invited to participate, of whom 2,190 submitted questionnaires. After data cleaning, questionnaires with duplicate submissions,

internally inconsistent responses, or other clearly invalid response patterns were excluded. Ultimately, 2,091 valid questionnaires were included in the final analysis.

Ethical approval

This study was approved by the Ethics Committee of Tianjin Eye Hospital (Approval No. KY-2024042). The study was conducted in accordance with the principles of the Declaration of Helsinki. Participation in the survey was voluntary and all responses were collected anonymously. Informed consent was obtained from all participants and their parents or legal guardians prior to participation.

Data collection

Data were collected using an electronic questionnaire distributed through the online survey platform Wenjuanxing. The questionnaire link and QR code were distributed to students in the selected classes through school communication channels, and participants voluntarily completed the questionnaire using their personal mobile devices. To improve data quality, the questionnaire was configured to allow only one submission per IP address, and all questions were required to be completed before submission, thereby reducing missing data and duplicate responses.

The questionnaire included sections on demographic characteristics, lifestyle behaviors, ocular symptoms, and medical history. Demographic variables included sex, ethnicity, and school stage. Lifestyle-related variables included daily screen time, daily outdoor activity duration, and sleep duration. Information regarding potential ocular and systemic factors was also collected, including refractive correction status, history of ocular trauma, allergic rhinitis or allergic conjunctivitis, history of hordeolum or chalazion, parental smoking, ocular medication use within the past 6 months, systemic diseases, and systemic medication use within the past 6 months.

Participants were also asked to report the presence of common ocular symptoms, including dryness, foreign body sensation, burning sensation, ocular discomfort, eye fatigue, redness, and fluctuating vision.

Assessment of dry eye symptoms

Dry eye symptoms were assessed using the OSDI questionnaire, a validated 12-item instrument designed to evaluate the frequency of dry eye symptoms and their impact on vision-related functioning [12]. Each item is scored on a scale from 0 to 4, and the total OSDI score ranges from 0 to 100, with higher scores indicating more severe symptoms. In this study, symptomatic DED was defined as an OSDI score ≥13, which has been widely used as a threshold in epidemiological studies.

Assessment of visual discomfort

Visual discomfort related to near work was evaluated using the Convergence Insufficiency Symptom Survey (CISS), a validated 15-item questionnaire designed to assess symptoms associated with

convergence insufficiency and visual fatigue during near tasks [13]. Each item is scored from 0 to 4, yielding a total score ranging from 0 to 60. A CISS score ≥16 was considered indicative of significant visual symptoms based on validation studies in children aged 9-18 years.

Statistical analysis

All statistical analyses were performed using SPSS software (version 23.0; IBM Corp., Armonk, NY, USA). Categorical variables were presented as frequencies and percentages. The prevalence of symptomatic DED was calculated based on an OSDI score ≥13.

Group differences between participants with and without symptomatic DED were initially assessed using the chi-square (χ^2) test for categorical variables. Because students were recruited through classes, generalized estimating equation (GEE) logistic regression models were used to account for potential within-class correlation. Odds ratios (ORs) and 95% confidence intervals (CIs) were estimated using a binomial distribution, a logit link function, an exchangeable working correlation structure, and robust standard errors, with class ID specified as the clustering variable. Variables with $P < 0.05$ in univariate analyses were included in the multivariable GEE logistic regression model. Model 1 was constructed to identify factors independently associated with symptomatic DED. Ocular medication use was excluded from the multivariable model because of the potential for reverse causality. To address the potential influence of overlapping symptom constructs, Model 2 additionally included CISS (≥16 vs. <16). All statistical tests were two-sided, and a P value <0.05 was considered statistically significant.

Results

Participant characteristics and prevalence of symptomatic DED

A total of 2,250 students were invited to participate, and 2,190 questionnaires were submitted, yielding a submission rate of 97.3%. After exclusion of 99 invalid questionnaires, 2,091 valid questionnaires were included in the final analysis, corresponding to an overall valid response rate of 92.9%. The participant flow is shown in Figure 1.

Among these participants, 321 were identified as having symptomatic DED, resulting in an overall prevalence of 15.4%. The baseline characteristics of the participants and the results of the univariate analysis are summarized in Table 1.

School stage was significantly associated with symptomatic DED, with middle school students showing a higher prevalence compared to high school students (16.4% vs. 11.9%, $P = 0.015$). Sex and ethnicity were not significantly associated with symptomatic DED ($P = 0.079$ and $P = 0.345$, respectively). Students with more than 2 hours of daily screen time had a significantly higher prevalence of symptomatic DED than those with £2 hours (22.3% vs. 13.3%, OR = 1.87, 95% CI: 1.45–2.43, $P < 0.001$). Similarly, shorter outdoor activity time (£2 h/day) was associated with higher odds of symptomatic DED (OR = 1.52, 95% CI: 1.11–2.09, $P = 0.010$). Sleep duration was also significantly associated with

symptomatic DED, with students sleeping <6 hours showing the highest odds (OR = 2.96, 95% CI: 1.70–5.17, *P* < 0.001), followed by those sleeping 6-8 hours (OR = 1.58, 95% CI: 1.03–2.44, *P* = 0.038), compared to those sleeping >8 hours. Several clinical and ocular-related factors were significantly associated with symptomatic DED. Students with a CISS score ≥16 were substantially more likely to report symptomatic DED in the univariate analysis (OR = 126.26, 95% CI: 59.26–269.02, *P* < 0.001). In addition, a history of allergic rhinitis or allergic conjunctivitis (OR = 1.75, 95% CI: 1.38–2.23, *P* < 0.001), hordeolum or chalazion (OR = 1.73, 95% CI: 1.24–2.42, *P* = 0.001), and ocular medication use in the past 6 months (OR = 2.90, 95% CI: 2.07–4.07, *P* < 0.001) were all significantly associated with symptomatic DED. In contrast, refractive correction status, parental smoking, ocular trauma history, systemic disease, and systemic medication use were not significantly associated with symptomatic DED (all *P* > 0.05).

Table 1. Baseline characteristics of participants and univariate analysis of factors associated with symptomatic DED (N = 2091)

Variable	Total (N)	DED n (%)	Crude OR (95% CI)	χ^2	*P* value
Sex				3.095	0.079
Male	1091	153 (14.0)	1.00 (Ref)		
Female	1000	168 (16.8)	1.24 (0.98–1.57)		
Ethnicity				0.892	0.345
Other ethnicities	157	20 (12.7)	1.00 (Ref)		
Han ethnicity	1934	301 (15.6)	1.26 (0.78–2.05)		
School stage				5.886	0.015
High school	488	58 (11.9)	1.00 (Ref)		
Middle school	1603	263 (16.4)	1.46 (1.07–1.97)		
Refractive correction status				6.019	0.111
No refractive error	830	131 (15.8)	1.00 (Ref)		
Uncorrected refractive error	325	58 (17.8)	1.16 (0.83–1.63)		
Spectacle correction	653	83 (12.7)	0.78 (0.58–1.05)		
Contact lens correction	283	49 (17.3)	1.12 (0.78–1.60)		
Screen time				23.246	<0.001
≤2 h/day	1606	213 (13.3)	1.00 (Ref)		
>2 h/day	485	108 (22.3)	1.87 (1.45–2.43)		
Outdoor activity				6.692	0.010
>2 h/day	446	51 (11.4)	1.00 (Ref)		
≤2 h/day	1645	270 (16.4)	1.52 (1.11–2.09)		
Sleep duration				15.916	<0.001

>8 h/day	245	25 (10.2)	1.00 (Ref)		
6-8 h/day	1699	259 (15.2)	1.58 (1.03–2.44)		
<6 h/day	147	37 (25.2)	2.96 (1.70–5.17)		
CISS score				596.307	<0.001
CISS <16	1313	7 (0.5)	1.00 (Ref)		
CISS ≥16	778	314 (40.4)	126.26 (59.26–269.02)		
Parental smoking				0.026	0.873
No	1467	224 (15.3)	1.00 (Ref)		
Yes	624	97 (15.5)	1.02 (0.79–1.32)		
Ocular trauma history				1.747	0.186
No	2062	314 (15.2)	1.00 (Ref)		
Yes	29	7 (24.1)	1.77 (0.75–4.18)		
History of allergic rhinitis or conjunctivitis				21.509	<0.001
No	1235	152 (12.3)	1.00 (Ref)		
Yes	856	169 (19.7)	1.75 (1.38–2.23)		
History of hordeolum or chalazion				10.474	0.001
No	1861	269 (14.5)	1.00 (Ref)		
Yes	230	52 (22.6)	1.73 (1.24–2.42)		
Ocular medication use (past 6 months)				41.219	<0.001
No	1908	263 (13.8)	1.00 (Ref)		
Yes	183	58 (31.7)	2.90 (2.07–4.07)		

Systemic disease				1.155	0.282
No	2075	317 (15.3)	1.00 (Ref)		
Yes	16	4 (25.0)	1.85 (0.59–5.77)		
Systemic medication (past 6 months)				2.063	0.151
No	2068	315 (15.2)	1.00 (Ref)		
Yes	23	6 (26.1)	1.96 (0.77–5.02)		

Abbreviations: OR, odds ratio; CI, confidence interval; DED, dry eye disease; CISS, Convergence Insufficiency Symptom Survey.
Note: Data are presented as number (percentage). Crude ORs and 95% CIs were calculated using univariate logistic regression models. Chi-square tests were used to compare categorical variables between groups. Reference categories (Ref) are specified for each variable. A two-sided *P* value < 0.05 was considered statistically significant.

Prevalence of ocular symptoms

The distribution of ocular symptoms among participants with and without symptomatic DED is summarized in Table 2 and illustrated in Figure 2.

All assessed ocular symptoms were significantly more prevalent in participants with symptomatic DED than in those without symptomatic DED (all $P < 0.001$). Notably, dryness was reported by 69.8% of participants in the symptomatic DED group, compared with 25.8% in the non-symptomatic DED group ($\chi^2 = 239.93$, $P < 0.001$). Similarly, foreign body sensation was substantially more frequent among participants with symptomatic DED (36.1% vs. 6.2%, $\chi^2 = 252.37$, $P < 0.001$), as was burning sensation (11.5% vs. 1.6%, $\chi^2 = 86.91$, $P < 0.001$). Ocular discomfort was reported by 68.5% of participants with symptomatic DED, which was markedly higher than the 22.0% observed in the non-symptomatic DED group ($\chi^2 = 285.34$, $P < 0.001$). Eye fatigue emerged as the most commonly reported symptom in the symptomatic DED group (83.8%), compared with 36.8% among those without symptomatic DED ($\chi^2 = 243.82$, $P < 0.001$). In addition, redness was more prevalent in participants with symptomatic DED (27.7% vs. 7.4%, $\chi^2 = 119.23$, $P < 0.001$). Furthermore, fluctuating vision showed a pronounced difference between groups, with 60.4% of participants with symptomatic DED reporting this symptom compared to 13.7% in the non-symptomatic DED group ($\chi^2 = 358.58$, $P < 0.001$). Overall, all assessed ocular symptoms were more frequently reported among participants with symptomatic DED, with eye fatigue, dryness, and ocular discomfort being the most commonly reported symptoms.

Table 2. Comparison of ocular symptoms between participants with and without symptomatic DED

Symptom	Non-DED n (%)	DED n (%)	χ^2	*P* value
Dryness	456 (25.8)	224 (69.8)	239.93	<0.001
Foreign body sensation	110 (6.2)	116 (36.1)	252.37	<0.001
Burning sensation	29 (1.6)	37 (11.5)	86.91	<0.001
Ocular discomfort	389 (22.0)	220 (68.5)	285.34	<0.001
Eye fatigue	651 (36.8)	269 (83.8)	243.82	<0.001
Redness	131 (7.4)	89 (27.7)	119.23	<0.001
Fluctuating vision	243 (13.7)	194 (60.4)	358.58	<0.001

Abbreviations: DED, dry eye disease.

Note: Data are presented as number (percentage). Comparisons between groups were performed using chi-square tests. All *P* values are two-sided, and $P < 0.05$ was considered statistically significant.

Multivariable GEE logistic regression analysis

Variables with $P < 0.05$ in the univariate analysis were included in the multivariable GEE logistic regression model. Ocular medication use within the past six months was excluded, as it likely reflects treatment after symptom onset rather than a causal factor. The results of the multivariable GEE logistic regression analysis are presented in Table 3. In model 1, history of allergic rhinitis/conjunctivitis (OR = 1.68, 95% CI: 1.28–2.20, $P < 0.001$), history of hordeolum/chalazion (OR = 1.63, 95% CI: 1.14–2.35, $P = 0.008$), middle school stage (OR = 1.75, 95% CI: 1.28–2.39, $P < 0.001$), screen time >2 h/day (OR = 1.91, 95% CI: 1.45–2.52, $P < 0.001$), outdoor activity ≤2 h/day (OR = 1.50, 95% CI: 1.06–2.11, $P = 0.023$), and sleep duration <6 h/day (OR = 2.53, 95% CI: 1.51–4.23, $P < 0.001$) were significantly associated with symptomatic DED. Sleep duration of 6–8 h/day was not significantly associated with symptomatic DED compared with >8 h/day (OR = 1.43, 95% CI: 0.89–2.32, $P = 0.143$).

In Model 2, after additional adjustment for CISS, history of allergic rhinitis/conjunctivitis (OR = 1.38, 95% CI: 1.03–1.85, $P = 0.033$), middle school stage (OR = 1.53, 95% CI: 1.09–2.14, $P = 0.014$), and screen time >2 h/day (OR = 1.67, 95% CI: 1.19–2.33, $P = 0.003$) remained significantly associated with symptomatic DED. In contrast, the associations for outdoor activity, sleep duration, and history of hordeolum/chalazion were attenuated and were no longer statistically significant. CISS showed a strong association with symptomatic DED (OR = 117.21, 95% CI: 56.43–243.23, $P < 0.001$), although this finding should be interpreted cautiously because of potential overlap in symptom constructs.

Table 3. Multivariable GEE logistic regression analysis of factors associated with symptomatic DED

	Model 1		Model 2	
Variable	Adjusted OR (95% CI)	*P* value	Adjusted OR (95% CI)	*P* value
Ocular factors				
History of allergic rhinitis / conjunctivitis (yes vs no)	1.68 (1.28–2.20)	<0.001	1.38 (1.03–1.85)	0.033
History of hordeolum/chalazion (yes vs no)	1.63 (1.14–2.35)	0.008	1.28 (0.81–2.02)	0.291
Lifestyle factors				
School stage (middle vs high)	1.75 (1.28–2.39)	0.001	1.53 (1.09–2.14)	0.014
Screen time (>2h vs ≤2 h)	1.91 (1.45–2.52)	<0.001	1.67 (1.19–2.33)	0.003
Outdoor activity (≤2 h vs >2h)	1.50 (1.06–2.11)	0.023	1.03 (0.66–1.62)	0.896
Sleep duration (<6 h vs >8 h)	2.53 (1.51–4.23)	<0.001	1.35 (0.75–2.44)	0.321
Sleep duration (6–8 h vs >8 h)	1.43 (0.89–2.32)	0.143	1.05 (0.61–1.80)	0.872
Sensitivity analysis variable				
CISS (yes vs no)			117.21 (56.43–243.23) *	<0.001

Model 1 represents the primary multivariable generalized estimating equation (GEE) logistic regression model. Model 2 additionally included CISS to evaluate the potential influence of overlapping symptom construct.

Abbreviations: OR, odds ratio; CI, confidence interval; CISS, Convergence Insufficiency Symptom Survey.

Reference groups: absence of convergence insufficiency, high school, screen time £2 h/day, outdoor activity >2 h/day, sleep duration >8 h/day, no history of allergic rhinitis/conjunctivitis, and no history of hordeolum/chalazion.

* The association estimate for CISS should be interpreted cautiously because both CISS and OSDI are symptom-based instruments with potentially overlapping constructs.

Discussion

This study investigated the prevalence of symptomatic DED and its associated factors among secondary school students in Heping District, Tianjin. The overall prevalence of symptomatic DED, defined by an OSDI score ≥13, was 15.4%. This finding supports the growing recognition that dry eye symptoms are not limited to older adults but can also affect children and adolescents [4]. Previous school-based studies have reported comparable findings. Uchino et al. found that severe dry eye symptoms were present in 21.0% of male and 24.4% of female Japanese high school students [14], while Garza-León et al. reported that dry eye symptoms were common among Mexican high school students assessed using the OSDI questionnaire [15]. Differences across studies may reflect variations in diagnostic criteria, age distribution, and lifestyle factors such as digital device use.

A major finding of this study was the strong association between convergence insufficiency-related symptoms, as assessed by the CISS, and symptomatic DED. After additional adjustment for CISS in the multivariable GEE model, several associations were attenuated, whereas school stage, screen time, and allergic history remained significantly associated with symptomatic DED. Although CISS showed a strong association with symptomatic DED, this finding should be interpreted cautiously because both CISS and OSDI are symptom-based instruments and likely share overlapping symptom domains. Thus, CISS may capture visual discomfort that overlaps with dry eye symptomatology rather than represent an independent etiological determinant. This interpretation is supported by previous evidence showing that convergence insufficiency is associated with eye strain, blurred vision, and discomfort during prolonged near work[16]. Prolonged near work may also reduce blink rate and destabilize the tear film, thereby exacerbating dry eye symptoms. Consistent with our findings, Soltan Dehghan et al. reported a significant association between convergence insufficiency and dry eye symptoms[17]. Taken together, these findings suggest that sustained near work and digital device use may underlie the observed coexistence of visual fatigue and ocular surface discomfort. Clinically, adolescents with persistent ocular complaints may benefit from evaluation of both ocular surface status and binocular vision function. Future studies incorporating objective measures of binocular vision and ocular surface parameters are warranted.

Another significant factor associated with symptomatic DED was a history of allergic rhinitis or allergic conjunctivitis. Students with allergic conditions had higher odds of experiencing dry eye symptoms, consistent with evidence that allergic inflammation can disrupt tear film homeostasis and adversely affect the ocular surface in pediatric populations. Children with allergic conjunctivitis have been reported to show reduced tear film stability and morphological alterations of the meibomian glands[18]. Structural evidence also suggests that allergic ocular disease may be associated with increased meibomian gland atrophy, with greater severity linked to untreated disease duration and electronic screen exposure[19]. In addition, children with systemic allergic diseases may exhibit subclinical ocular surface abnormalities, including shorter noninvasive tear breakup time and increased meibomian gland atrophy[20]. Chronic ocular itching and eye rubbing may further aggravate ocular surface irritation. Together, these findings indicate that allergic conditions should be considered when evaluating dry eye symptoms in adolescents.

Interestingly, high school students had lower odds of symptomatic DED than middle school students in the present study. This pattern differs from adult populations, in which the prevalence of symptomatic DED generally increases with age[2]. In younger populations, however, behavioral and environmental factors may play a larger role in ocular surface health[4,10]. Differences in digital device use, near-work behavior, and visual habits across school stages may partly explain this finding. At the same time, the relatively smaller number of high school students compared with middle school students may have affected the stability and precision of the estimates. Therefore, the lower prevalence observed among high school students should be interpreted cautiously, and further longitudinal studies are needed to clarify the relationships between age, behavior, and dry eye symptoms in younger populations.

Daily screen exposure was also significantly associated with symptomatic DED. Students reporting more than two hours of screen time per day had significantly higher odds of dry eye symptoms, consistent with previous studies in pediatric and adolescent populations[21,22]. Mechanistically, prolonged digital device use may alter blinking behavior, including reduced blink rate and increased incomplete blinking, thereby increasing tear film instability and evaporation[10]. Sustained visual attention during near tasks may further disrupt tear film homeostasis[4]. Experimental evidence in school-aged children has shown that even one hour of smartphone use can rapidly worsen ocular discomfort and significantly reduce blink rate, despite no immediate changes in tear film parameters[23]. These findings support the role of digital screen exposure in the development of dry eye-related symptoms and suggest that healthier screen-use behaviors may help reduce symptom burden among adolescents.

In the primary multivariable GEE model, shorter outdoor activity time and sleep duration <6 h/day remained significantly associated with symptomatic DED. However, these associations were attenuated after additional adjustment for CISS and were no longer statistically significant. This pattern suggests that the observed associations of sleep and outdoor activity with symptomatic DED may be partly influenced by overlapping symptom burden and related behavioral factors. Previous studies have emphasized that DED in children and adolescents is multifactorial, with digital device use, environmental exposure, and behavioral patterns acting together to influence ocular surface health[4,10]. Digital eye strain and poor sleep quality also frequently coexist in adolescents and share common behavioral risk factors, particularly excessive digital media use[24]. Thus, sleep and outdoor activity may reflect broader lifestyle patterns rather than act independently, and their relationships with symptomatic DED should be interpreted cautiously.

The observed association between ocular medication use and symptomatic DED should also be interpreted with caution, as it may reflect reverse causality. Students experiencing ocular discomfort are more likely to use eye drops, so this variable may represent a marker of underlying symptoms or pre-existing ocular conditions rather than a causal factor.

In this study, eye fatigue was the most commonly reported symptom, followed by dryness and ocular discomfort. This pattern likely reflects the important contribution of visual function–related strain in adolescents, particularly during sustained near work and digital device use. Updated perspectives on

digital eye strain have highlighted a broad spectrum of symptoms, including eye strain, redness, burning, blurred vision, and dryness, and have emphasized the role of reduced blink frequency in linking screen exposure to ocular surface discomfort[25]. In light of the strong association between convergence insufficiency symptoms and symptomatic DED observed here, visual fatigue may represent a central component of the symptom profile in this population. Consistent with this interpretation, previous studies have shown that visual fatigue frequently coexists with ocular surface–related discomfort in children and adolescents[7,15].

This study has several notable strengths. Validated instruments, including the OSDI and CISS, were used to assess dry eye symptoms and convergence insufficiency-related symptom burden, thereby enhancing the reliability and comparability of the findings. The relatively large sample size drawn from an urban school district improved statistical power and supported the relevance of the findings to similar urban adolescent populations. In addition, a broad range of potential risk factors was examined, allowing for a more comprehensive evaluation of factors associated with symptomatic DED in adolescents. Nevertheless, several limitations should be acknowledged. First, the cross-sectional design precludes causal inference. Second, all data were self-reported and may therefore be affected by recall and reporting bias. Third, the use of symptom-based instruments for both exposure and outcome variables may introduce common method bias, potentially inflating observed associations. Finally, symptomatic DED was assessed using questionnaire data rather than objective clinical examinations, and clinical DED could therefore not be confirmed.

In conclusion, symptomatic DED was common among secondary school students in this study and was associated with allergic conditions and increased screen exposure. The strong association observed with convergence insufficiency-related symptoms likely reflects overlapping symptom profiles rather than a direct causal relationship. These findings highlight the importance of considering both ocular surface symptoms and visual function-related discomfort when evaluating ocular complaints in adolescents. Future studies incorporating objective clinical assessments and longitudinal designs are warranted to further clarify these relationships.

Abbreviations

OR
odds ratio
CI
confidence interval
DED
dry eye disease
CISS
Convergence Insufficiency Symptom Survey.

Declarations

Data availability

The datasets generated and analyzed during the current study are not publicly available due to privacy and ethical restrictions involving minors, but are available from the corresponding author on reasonable request. All requests for data access will be reviewed by the institutional ethics committee to ensure compliance with data protection regulations and the ethical approval of the study.

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Author contributions

Lu Tian conceived and designed the study and drafted the manuscript. Lu Tian, Xiaoyan Yang, Jinrong Zhao, Yanglin Jiang, Xin Chen, Zhiyan Ji, Xinyu Yang, Bochen Gao, and Changqi Li participated in data collection and investigation. Lu Tian and Xiaoyan Yang performed the statistical analyses. Lihua Li and Quanhong Han critically revised the manuscript. All authors read and approved the final manuscript.

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Additional Information

Competing interests

The authors declare no competing interests.

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Figures

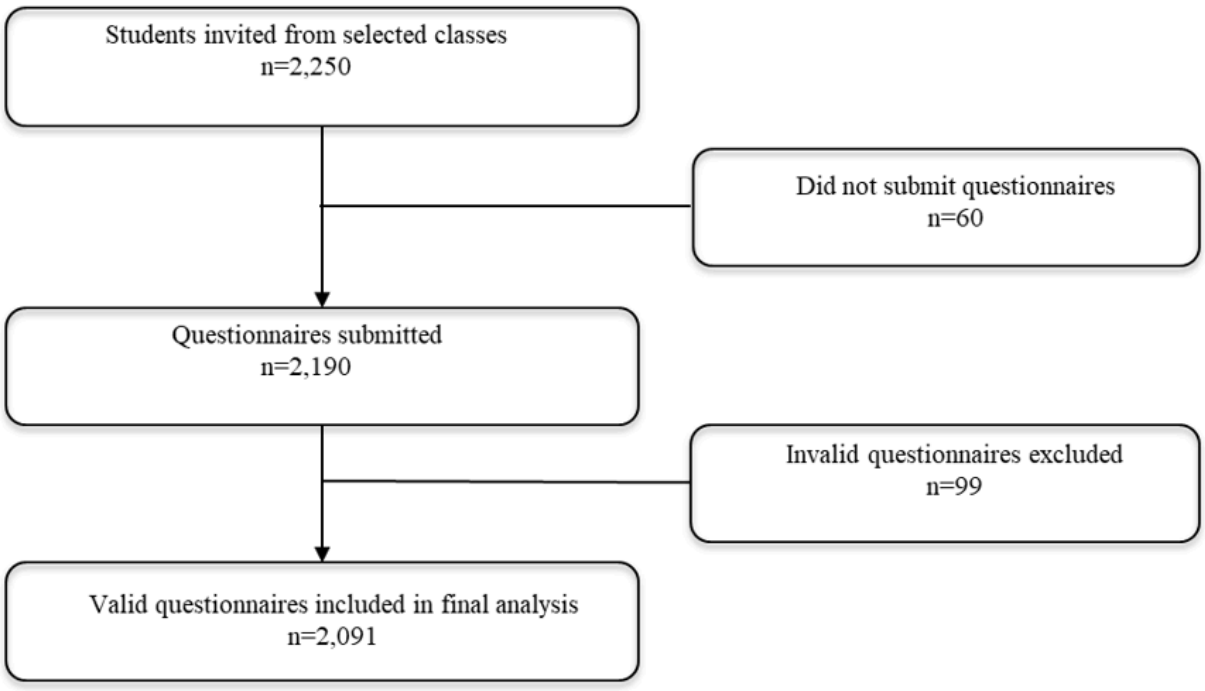


Figure 1

Flow diagram of participant recruitment and inclusion

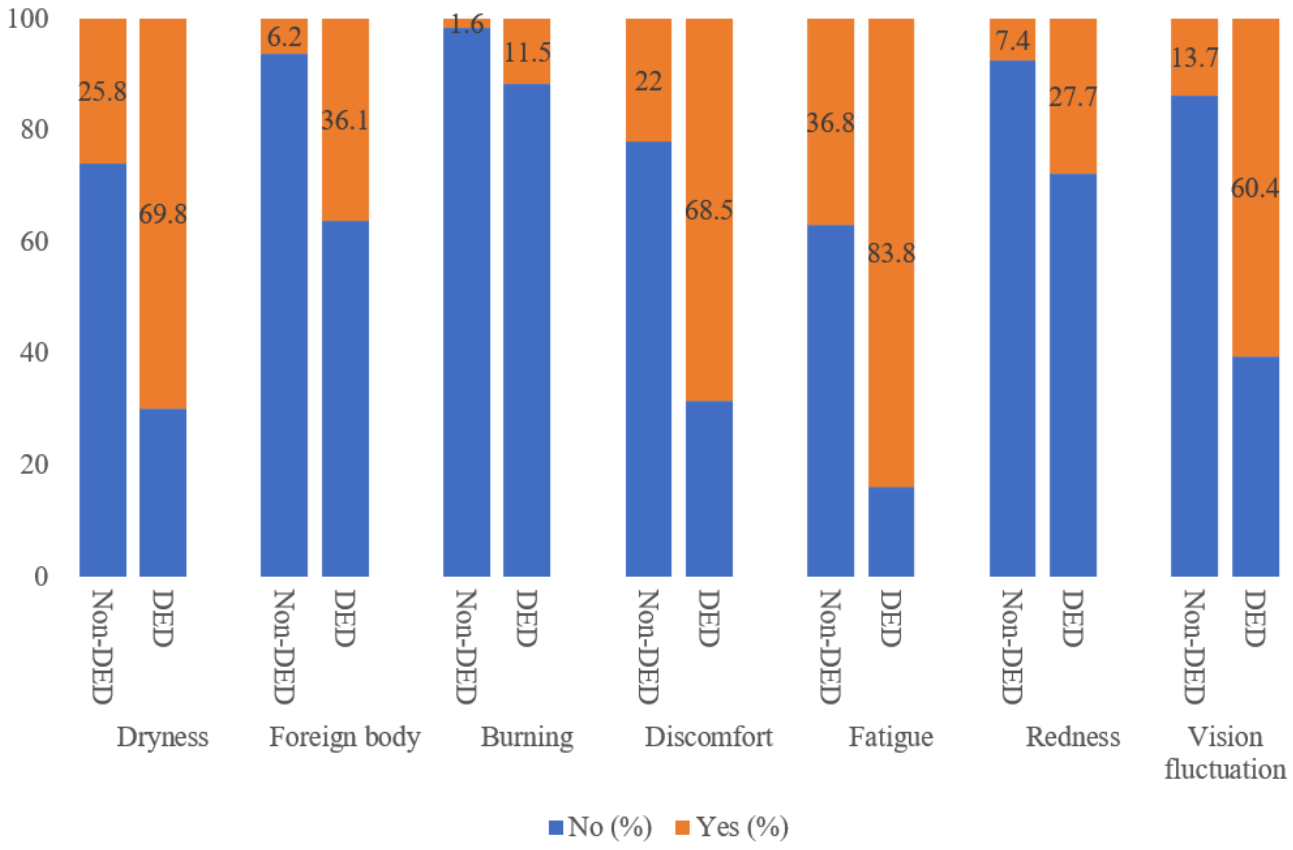


Figure 2

Distribution of ocular symptoms in participants with and without symptomatic DED.

Stacked bar charts illustrate the proportion of participants reporting each symptom (yes/no) in the symptomatic DED and non-symptomatic DED groups. Percentages are calculated within each group for each symptom.