Association of different digital media experiences with paediatric dry eye in China: a population-based study

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ABSTRACT

Objective To investigate the ocular surface effects of different digital media experiences in Chinese elementary school students.

Design Population-based cross-sectional study was used.

Setting 14 randomly selected primary schools in Yuhuatai District, Nanjing, China.

Participants 2,694 students between 7 and 8-year-old.

Outcome Measures Prevalence of and risk factors for different types of dry eye disease, and different digital media experience with different ocular signs.

Results The prevalence of ‘symptomatic DED’ was 8.7% (95% CI 7.6% to 9.8%) and ‘definite DED’ prevalence rate was 5.5% (95% CI 4.7% to 6.4%). In multivariable logistic regression model, allergic conjunctivitis (OR=4.33, 95% CI (3.01 to 6.23), p<0.001), more than 1 hour per day on outdoor activity (OR=0.69, 95% CI (0.49 to 0.99), p=0.043), smartphone (OR=2.73, 95% CI (1.51 to 4.91), p=0.001), tablet (OR=2.09, 95% CI (1.02 to 4.07), p=0.044) and homework (OR=1.86, 95% CI (1.22 to 2.83), p=0.004) were independently associated with ‘definite DED’, while allergic conjunctivitis (OR=5.58, 95% CI (4.12 to 7.55), p<0.001) more than 1 hour per day on outdoor activity (OR=0.72, 95% CI (0.53 to 0.97), p=0.028), smartphone (OR=2.60, 95% CI (1.55 to 4.35), p=0.001), tablet (OR=1.84, 95% CI (1.02 to 3.34), p=0.044) and homework (OR=2.57, 95% CI (1.84 to 3.60), p<0.001) were independently associated with ‘symptomatic DED’.

Conclusions Using smartphones or tablets for an average of more than 1 hour per day through the course of a year is independently associated with paediatric DED.

INTRODUCTION

Dry eye disease (DED) is defined as multifactorial damage to the ocular surface characterised by declining tear film homeostasis and accompanied by ocular symptoms. DED is widely encountered in ophthalmic practice and recognised as a substantial public health problem.3 According to a Tear Film & Ocular Surface Society (TFOS) Dry Eye Workshop II (DEWS II) report, the prevalence of DED involving symptoms with or without signs ranged from 5% to 50% across various regions and populations.4 Only a few studies included the younger population since most epidemiological studies were conducted in adults aged 20–96 years.3–6 A retrospective study in 2019 using the Department of Defense Military Health System data reported that DED prevalence according to a combination of diagnoses, procedures and/or prescription fills amounted to 0.20% for children aged 2–17 years old, whereas it did not reveal the prevalence among younger children.7 Since the Asian race is a common risk factor for DED,5 a hospital-based cross-sectional study published in 2020 reported that among 259,969 children and adolescents (aged <21 years) from 2010 to 2018 years in India, there were 49 (4.79%) people aged 3–5 years and 166 (16.23%) people aged 6–11 years with dry eyes as per the TFOS DEWS II criteria.8 A much higher prevalence (21%–24%) based on the Women’s Health Study (WHNS) criteria (severe symptoms of dryness and irritation and/or a physician’s diagnosis of dry eye) as reported by the participant was found in two studies among senior high school students in China and Japan.4,5 Due to an increase in...
dry eye prevalence with age, another study conducted in Japan demonstrated that the prevalence of DED based on the WHS criteria was 6.7% in elementary school children and 16.4% in junior high school children in 2019. The fluctuation in the prevalence rate of DED could be due to differences in diagnostic criteria, study population and methodology. Owing to the limited number and variable findings of prevalence studies in youth, the number of young patients accounts for a significant proportion of the patient population, and this remains an important area for further research.

Since the development of numerous new kinds of digital display screens (such as televisions, smartphones, tablets and computers), which may differ in terms of viewing position, size, method and pattern of use, a short-term ocular surface discomfort and visual discomfort that could be induced by smartphones were reported in several case–control studies. In contrast, the long-term ocular surface effects entailed by using different digital devices by the young population were still unknown. In this population-based cross-sectional study, the prevalence and risk factors of DED among Chinese elementary school students aged 7 and 8 years old were determined. In particular, the associations between different digital media experiences and DED were evaluated.

METHODS
Study design and population
This population-based cross-sectional study was conducted from April to November of 2019 in Yuhuatai District, Nanjing, China. The Yuhuatai District is an urban area in Nanjing with a medium level of socioeconomic development, which is representative of Eastern China.

Questionnaires
Subjective ocular symptoms were evaluated with the Chinese version of the modified Ocular Surface Disease Index (OSDI), which has been acknowledged as the most common DED-specific questionnaire and validated in Chinese language, consisting of 11 questions to measure the frequency of ocular symptoms, vision-related functions and limitation, and environmental triggers in the previous week. The question about night driving was omitted as children are not expected to drive during night time. Each response was scored using a 5-point scale whereby 0 indicates no problem and 4 indicates a significant problem. The total OSDI score was calculated as follows: (sum of scores×25/11) and ranged from 0 to 100. Based on their OSDI scores, the students were classified as asymptomatic (0≤scores <13 points), mild (13≤scores <22 points), moderate (22≤scores <33 points) and severe (33≤scores <100 points) symptomatic DED. Parents acted as guides and explained the meaning of the questionnaire to the children orally. The parents then completed the OSDI and detailed questionnaires on their children’s behalf to collect information regarding their lifestyles in the past 12 months to assess the potential risk factors for DED.

Ocular examinations
Ophthalmic examinations were performed by a team composed of trained ophthalmologists and optometrists, including distance visual acuity (VA), non-cycloplegic refraction and slit-lamp examination. Distance VA was measured using the Early Treatment Diabetic Retinopathy Study VA chart at 4 m. In case glasses were worn, distance VA was measured both with and without glasses. Non-cycloplegic refraction was performed with the table-mounted auto-refractor (R-F10, Cannon, Tokyo, Japan).

A slit-lamp examination was used to assess eyelid health, anterior segments, the tear break-up time (TBUT) and the corneal fluorescein staining scores (CFSS). For TBUT, fluorescein strips wetted with one drop (less than 2 µL) of balanced salt solution were gently dripped to the temporal inferior conjunctival fornix, and the participants were required to blink three times to ensure adequate mixing of the dye with the tears. The time interval between the last blink and the appearance of the first dark spot on the cornea under slit-lamp examination with a blue filter was measured by a stopwatch and recorded as TBUT in seconds. The average of three measurements was used to boost the accuracy of the results. For CFSS, the entire cornea was divided into five corneal zones: superior, inferior, nasal, temporal and central. CFSS was graded on a scale from 0 (no staining) to 4 (coalesced staining over half the zone or more) separately in the five corneal zones. The total score of five zones was subsequently used for analysis.

Inclusion and exclusion criteria
All children between 7 and 8 years old from 14 randomly selected primary schools who were able to complete ocular examinations were included in this analysis and considered as the general study population. Children with a history of ocular surgery, congenital disorders, autoimmune diseases or inflammatory diseases were excluded from this study.

Definitions
‘Definite DED’ was defined based on symptoms and signs according to a consensus reported by the Asia Dry Eye Society as follows: (1) subjective symptoms: an OSDI score ≥13 points; and (2) objective signs: TBUT ≤5 s. Assessment for the ocular surface damage and tear production is not required for defining DED as per the new criteria stipulated by the Asia Dry Eye Society. Once subjective symptoms and objective signs appeared in any one of the two eyes, the child was considered having ‘definite DED’. Meanwhile, a student with an OSDI score ≥15 points was considered to have ‘symptomatic DED’ regardless of showing the objective signs of DED. ‘TBUT ≤5 s’ and ‘CFSS ≥1’ were considered as ‘abnormal dry eye signs’.  

Ma J, et al. BMJ Open 2022;12:e062850. doi:10.1136/bmjopen-2022-062850
Contact lens (CL) wear was defined as using CL at least once weekly in the previous 12 months. An inadequate refractive correction was defined as corrected VA less than 20/20 with glasses. A child who had a history of itchy/watery eyes and experienced at least 1 episode of such experience in the past 12 months was considered to have allergic conjunctivitis (AC).

**Statistical analysis**

All statistical analyses were performed using the IBM SPSS program statistical package V.13.0. Two-sided p values less than 0.05 were considered statistically significant. The number of missing data is less than 5% of the number of total data. Descriptive statistics were presented using means±SD for continuous measures, and frequency count or percentage was used for the categorical measures. X² test was conducted to compare the categorical variables, Wilcoxon rank-sum test was performed to compare continuous measures and Spearman’s rank correlation analysis was carried out to evaluate the correlations between different values. The hours on different electronic devices, homework and outdoor exercises were processed as categorical variables (≤1 hour vs >1 hour/day); this categorisation is based on a previous Korean population-based study of adolescents that concluded that longer smartphone use (>2 hours/day) was associated with a higher risk of dry eye symptoms. Given that the children in this study were younger than adolescents, the average time spent using each electronic device per day was lower; hours on each electronic device were classified as >1 hour or 1 hour. To determine risk factors for ‘definite DED’ and ‘symptomatic DED’, univariable logistic regression models were first performed, and all variables in univariable analysis were included in the multivariable logistic regression model. Risk factors for OSDI, TBUT and CFSS (as continuous) used Cox proportional hazards regression models. The model went through ‘enter’ variable selection to keep all risk factors in the final multivariable logistic regression model. Risk factors for OSDI, TBUT and CFSS (as continuous) used univariable and multivariable linear regression models. The model underwent the ‘enter’ variable selection to keep all risk factors in the final multivariable linear regression model. Ordinal logistic regression analysis is used to investigate the association between different digital devices and the various levels of OSDI, with children classified into asymptomatic, mild, moderate and severe symptomatic groups based on their OSDI level. The link between varied digital media usage and various dry eye signs was evaluated using binary logistic regression. The ORs and 95% CIs from logistic regression models were used to evaluate the associations between risk factors and DED.

**Patient and public involvement**

Neither patients nor the public were involved in any aspects of the study, including the development of study question, study design, conduct of the study and dissemination of results.

No additional data available.
eyes among all subjects. The eye with shorter TBUT was considered as the worse eye. Characteristics of the worse eye in children with ‘definite DED’ or ‘symptomatic DED’ are shown in table 1.

Figure 2 illustrates the gender distribution according to the severity of OSDI levels. The number of children classified as asymptomatic, mild, moderate and severe symptomatic group was 2460 (male:female=46.8%:53.2%), 126 (male:female=39.7%:60.3%), 70 (male:female=38.6%:61.4%) and 38 (male:female=36.8%:63.2%), respectively. No difference was noted in the severity of OSDI symptoms of DED in gender (p=0.137). The OSDI score was not correlated with TBUT (R=−0.01, p=0.81) and CFSS (R=−0.01, p=0.51).

Risk factors for ‘symptomatic DED’ and ‘definite DED’

Univariable and multivariable logistic regression analyses for risk factors of ‘definite DED’ are listed in table 2. In the multivariable logistic regression model, AC (OR=4.33, 95% CI (3.01 to 6.23), p<0.001), more than 1 hour per day on outdoor activity (OR=0.69, 95% CI (0.49 to 0.97), p=0.043), smartphone (OR=2.73, 95% CI (1.51 to 4.91), p=0.001), tablet (OR=2.09, 95% CI (1.07 to 4.07), p=0.030) and homework (OR=1.86, 95% CI (1.22 to 2.83), p=0.004) were independently associated with ‘definite DED’.

Risk factors of ‘symptomatic DED’ are listed in table 3. In the final multivariable logistic regression model, AC (OR=5.58, 95% CI (4.12 to 7.55), p<0.001), more than 1 hour per day on outdoor activity (OR=0.72, 95% CI (0.53 to 0.97), p=0.028), smartphone (OR=2.60, 95% CI (1.55 to 4.35), p<0.001), tablet (OR=1.84, 95% CI (1.02 to 3.34), p=0.044) and homework (OR=2.57, 95% CI (1.84 to 3.61), p<0.001) were independently associated with ‘symptomatic DED’.

Table 1 Characteristics of the worse eye in children with ‘definite DED’ and ‘symptomatic DED’

| Characteristics | Non-definite DED | Definite DED | P value | Non-symptomatic DED | Symptomatic DED | P value |
|-----------------|------------------|-------------|---------|---------------------|----------------|---------|
| Subjects (N, %) | 2545 (94.47)     | 149 (5.53)  | 0.335*  | 2460 (91.3)         | 234 (8.69)     | 0.353*  |
| Mean ±SD age (year) | 7.50±0.50       | 7.46±0.50  |         | 7.50±0.50           | 7.47±0.50      |         |
| Male (%)       | 1360 (53.44)     | 91 (61.07)  | 0.069†  | 1308 (53.17)        | 143 (61.11)    | 0.020†  |
| OSDI           | 2.40±5.89        | 24.68±14.57| <0.001* | 1.62±2.91           | 24.83±15.18    | <0.001* |
| TBUT (seconds) | 5.58±2.28        | 3.99±0.72  | <0.001* | 5.51±2.27           | 5.35±2.08      | 0.492*  |
| CFSS           | 0.65±1.14        | 1.05±1.36  | <0.001* | 0.66±1.15           | 0.73±1.21      | 0.428*  |
| Outdoor activity (hour/day) | 1.79±0.89      | 1.70±0.91  | 0.137*  | 1.79±0.89           | 1.67±0.85      | 0.038*  |
| Time of watching TV (hour/day) | 0.85±0.72       | 1.04±0.89  | 0.016*  | 0.84±0.72           | 1.00±0.87      | 0.011*  |
| Time of using smartphone (hour/day) | 0.48±0.60       | 0.74±0.91  | 0.001*  | 0.47±0.60           | 0.71±0.85      | <0.001* |
| Time of using tablet (hour/day) | 0.42±0.56       | 0.59±0.67  | <0.001* | 0.41±0.56           | 0.55±0.63      | <0.001* |
| Time of using computer (hour/day) | 0.15±0.38       | 0.22±0.49  | 0.268*  | 0.15±0.38           | 0.21±0.49      | 0.241*  |
| Time of doing homework (hour/day) | 1.12±0.37       | 1.22±0.45  | 0.001*  | 1.12±0.36           | 1.27±0.49      | <0.001* |

*By Wilcoxon rank-sum test,
†By X² test.

CFSS, corneal fluorescein staining score; DED, dry eye disease; N, number; OSDI, Ocular Surface Disease Index; TBUT, tear break-up time.

Figure 2 The gender distribution according to the severity of Ocular Surface Disease Index (OSDI) levels.
## Table 2 Univariate and multivariate analyses for ‘definite dry eye disease (DED)’

| Risk factors                              | Definite DED (N=149), no (%) | Non-definite DED (N=2545), no (%) | Univariate | Multivariate | OR    | 95% CI | P value | OR    | 95% CI | P value |
|-------------------------------------------|------------------------------|-----------------------------------|------------|--------------|-------|-------|---------|-------|-------|---------|
| Gender                                    | Male                         | 91 (6.3)                          | 1360 (93.7) | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | Female                       | 58 (4.7)                          | 1185 (95.3) | 1.37          | 0.98 to 1.92 | 0.070 | 1.25  | 0.88 to 1.77 | 0.214  |
| Age (year)                                |                              | 7.47±0.50                         | 7.50±0.50   | 0.85          | 0.61 to 1.18 | 0.335 | 0.86  | 0.61 to 1.21 | 0.375  |
| Allergic conjunctivitis                   | No                           | 94 (4)                            | 2234 (96)   | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | Yes                          | 55 (15)                           | 311 (85)    | 4.20          | 2.95 to 5.98 | <0.001 | 4.33  | 3.01 to 6.23 | <0.001 |
| Contact lens wear                         | No                           | 147 (5.6)                         | 2478 (94.4) | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | Yes                          | 2 (2.9)                           | 66 (97.1)   | 0.51          | 0.12 to 2.10 | 0.353 | 0.52  | 0.12 to 2.17 | 0.367  |
| Inadequate refractive correction          | No                           | 143 (5.4)                         | 2496 (94.6) | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | Yes                          | 6 (10.9)                          | 49 (89.1)   | 2.14          | 0.90 to 5.07 | 0.085 | 2.10  | 0.85 to 5.19 | 0.109  |
| Outdoor activity (hour/day)*              | ≤1                           | 57 (6.8)                          | 779 (93.2)  | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | >1                           | 92 (5.0)                          | 1761 (95.0) | 0.71          | 0.51 to 1.00 | 0.053 | 0.69  | 0.49 to 0.99 | 0.043  |
| Time of watching TV (hour/day)*           | ≤1                           | 118 (5.1)                         | 2186 (94.9) | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | >1                           | 31 (8.1)                          | 353 (91.9)  | 1.63          | 1.08 to 2.45 | 0.020 | 1.29  | 0.79 to 2.11 | 0.312  |
| Time of using smartphone (hour/day)*      | ≤1                           | 128 (5.0)                         | 2415 (95.0) | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | >1                           | 21 (14.6)                         | 123 (85.4)  | 3.22          | 1.96 to 5.29 | <0.001 | 2.73  | 1.51 to 4.91 | 0.001  |
| Time of using tablet (hour/day)*          | ≤1                           | 135 (5.2)                         | 2447 (94.8) | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | >1                           | 14 (13.3)                         | 91 (86.7)   | 2.79          | 1.55 to 5.02 | 0.001 | 2.09  | 1.07 to 4.07 | 0.030  |
| Time of using computer (hour/day)*        | ≤1                           | 145 (5.5)                         | 2513 (94.5) | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | >1                           | 4 (14.3)                          | 24 (85.7)   | 2.89          | 0.99 to 8.44 | 0.052 | 1.18  | 0.35 to 4.04 | 0.787  |
| Time of doing homework (hour/day)*        | ≤1                           | 116 (5.0)                         | 2218 (95.0) | Ref           | Ref   | NA    | Ref     | Ref   | Ref   | NA      |
|                                           | >1                           | 33 (9.3)                          | 332 (90.7)  | 1.96          | 1.31 to 2.94 | 0.001 | 1.86  | 1.22 to 2.83 | 0.004  |
| Night sleeping time (hour/day, per hour increase) |      | 9.54±0.65       | 9.61±0.60       | 0.85          | 0.64 to 1.13 | 0.270 | 0.90  | 0.68 to 1.19 | 0.460  |

*The number of missing data is less than 5% of the number of total data.
N, number; NA, not applicable.
Risk factors of OSDI, TBUT and CFSS are listed in table 4. In the final multivariable linear regression model, AC (B=5.397, p<0.001), more daily hours on smartphone (B=1.026, p<0.001), tablet (B=0.905, p=0.002), homework (B=2.252, p<0.001) and outdoor activity (B=−0.635, p<0.001) were independently associated with OSDI. More daily hours on watching television (B=0.231, p=0.001) was the only factor independently associated with TBUT in multivariate linear regression models. No factor was found associated with CFSS.

| Risk factors                      | Symptomatic DED (N=234), no (%) | Non-symptomatic (N=2460), no (%) | Univariate OR 95% CI P value | Multivariate OR 95% CI P value |
|-----------------------------------|---------------------------------|----------------------------------|-----------------------------|-----------------------------|
| Gender                            |                                 |                                  |                             |                             |
| Male                              | 143 (9.9)                       | 1308 (90.1)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| Female                            | 91 (7.3)                        | 1152 (82.7)                      | 1.38                         | 1.05 to 1.82                 | 0.020                        | 1.22                         | 0.91 to 1.62                 | 0.184                        |
| Age (year)                        | 7.47±0.50                       | 7.50±0.50                        | 0.88                         | 0.68 to 1.15                 | 0.354                        | 0.87                         | 0.66 to 1.16                 | 0.350                        |
| Allergic conjunctivitis           |                                 |                                  |                             |                             |                             |                             |                             |                             |
| No                                | 141 (6.1)                       | 2187 (93.9)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| Yes                               | 93 (25.4)                       | 273 (74.6)                       | 5.28                         | 3.95 to 7.07                 | <0.001                       | 5.58                         | 4.12 to 7.55                 | <0.001                       |
| Contact lens wear                 |                                 |                                  |                             |                             |                             |                             |                             |                             |
| No                                | 229 (8.7)                       | 2397 (91.3)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| Yes                               | 5 (7.4)                         | 63 (92.6)                        | 0.83                         | 0.33 to 2.09                 | 0.692                        | 0.87                         | 0.34 to 2.25                 | 0.772                        |
| Inadequate refractive correction  |                                 |                                  |                             |                             |                             |                             |                             |                             |
| No                                | 228 (8.6)                       | 2411 (91.4)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| Yes                               | 6 (10.9)                        | 49 (89.1)                        | 1.30                         | 0.55 to 3.06                 | 0.555                        | 1.29                         | 0.52 to 3.20                 | 0.587                        |
| Outdoor activity (hour/day)*      |                                 |                                  |                             |                             |                             |                             |                             |                             |
| ≤1                                | 88 (10.5)                       | 747 (89.5)                       | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| >1                                | 146 (7.9)                       | 1708 (92.1)                      | 0.73                         | 0.55 to 0.96                 | 0.025                        | 0.72                         | 0.54 to 0.97                 | 0.028                        |
| Time of watching TV (hour/day)*   |                                 |                                  |                             |                             |                             |                             |                             |                             |
| ≤1                                | 191 (8.3)                       | 2113 (91.7)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| >1                                | 43 (11.2)                       | 341 (88.8)                       | 1.40                         | 0.98 to 1.98                 | 0.062                        | 1.21                         | 0.80 to 1.85                 | 0.363                        |
| Time of using smartphone (hour/day)*|                                 |                                  |                             |                             |                             |                             |                             |                             |
| ≤1                                | 206 (8.1)                       | 2337 (91.9)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| >1                                | 28 (19.4)                       | 116 (80.6)                       | 2.74                         | 1.77 to 4.24                 | <0.001                       | 2.60                         | 1.55 to 4.35                 | <0.001                       |
| Time of using tablet (hour/day)*  |                                 |                                  |                             |                             |                             |                             |                             |                             |
| ≤1                                | 216 (8.4)                       | 2366 (91.6)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| >1                                | 18 (17.1)                       | 87 (82.9)                        | 2.27                         | 1.34 to 3.84                 | 0.002                        | 1.84                         | 1.02 to 3.34                 | 0.044                        |
| Time of using computer (hour/day)*|                                 |                                  |                             |                             |                             |                             |                             |                             |
| ≤1                                | 228 (8.6)                       | 2430 (91.4)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| >1                                | 6 (21.4)                        | 22 (78.6)                        | 2.91                         | 1.17 to 7.24                 | 0.022                        | 1.44                         | 0.50 to 4.17                 | 0.501                        |
| Time of doing homework (hour/day)*|                                 |                                  |                             |                             |                             |                             |                             |                             |
| ≤1                                | 172 (7.4)                       | 2162 (92.6)                      | Ref                          | Ref                          | NA                           | Ref                          | Ref                          | NA                           |
| >1                                | 62 (17.5)                       | 293 (82.5)                       | 2.66                         | 1.94 to 3.64                 | <0.001                       | 2.57                         | 1.84 to 3.60                 | <0.001                       |
| Night sleeping time (hour/day, per hour increase) | 9.54±0.65 | 9.61±0.60 | 0.80 | 0.64 to 1.02 | 0.069 | 0.88 | 0.70 to 1.12 | 0.306 |

*The number of missing data is less than 5% of the number of total data. N, number; NA, not applicable.
**Table 4**  Risk factors for Ocular Surface Disease Index (OSDI), tear break-up time (TBUT) and corneal fluorescein staining scores (CFSS)

| Risk factors                  | **OSDI** |             |             | **TBUT** |             |             | **CFSS** |             |             |
|-------------------------------|----------|-------------|-------------|----------|-------------|-------------|----------|-------------|-------------|
|                               | Univariate | Multivariate | Univariate | Multivariate | Univariate | Multivariate | Univariate | Multivariate | Univariate |
|                               | B        | P value     | B          | P value     | B          | P value     | B          | P value     | B          |
| Gender                        |          |             |            |            |            |             |            |             |            |
| Male                          | Ref      | NA          | Ref        | NA          | Ref        | NA          | Ref        | NA          | Ref        |
| Female                        | 0.720    | 0.026       | 0.455      | 0.148      | −0.014     | 0.874       | −0.022     | 0.799       | 0.002      | 0.972      | 0.000      | 0.998      |
| Age (year)                    | −0.355   | 0.273       | −0.389     | 0.214      | 0.157      | 0.070       | 0.150      | 0.086       | −0.002     | 0.969      | −0.007     | 0.869      |
| Allergic conjunctivitis       |          |             |            |            |            |             |            |             |            |
| No                            | Ref      | NA          | Ref        | NA          | Ref        | NA          | Ref        | NA          | Ref        |
| Yes                           | 5.230    | <0.001      | 5.397      | <0.001      | −0.087     | 0.494       | −0.048     | 0.709       | 0.100      | 0.125      | 0.104      | 0.116      |
| Contact lens wear             |          |             |            |            |            |             |            |             |            |
| No                            | Ref      | NA          | Ref        | NA          | Ref        | NA          | Ref        | NA          | Ref        |
| Yes                           | 0.866    | 0.401       | 0.849      | 0.393      | −0.053     | 0.849       | −0.075     | 0.788       | 0.235      | 0.099      | 0.242      | 0.089      |
| Inadequate refractive correction |          |             |            |            |            |             |            |             |            |
| No                            | Ref      | NA          | Ref        | NA          | Ref        | NA          | Ref        | NA          | Ref        |
| Yes                           | 0.425    | 0.710       | 0.469      | 0.670      | −0.002     | 0.995       | 0.005      | 0.988       | 0.024      | 0.881      | 0.018      | 0.909      |
| Outdoor activity (hour/day)   | −0.547   | 0.003       | −0.635     | <0.001     | 0.031      | 0.525       | 0.010      | 0.840       | 0.008      | 0.738      | 0.015      | 0.559      |
| Time of watching television (hour/day) | 0.529    | 0.017       | 0.208      | 0.396      | 0.210      | <0.001     | 0.231      | 0.001       | −0.036     | 0.244      | −0.056     | 0.110      |
| Time of using smartphone (hour/day) | 1.188    | <0.001      | 1.026      | <0.001     | 0.057      | 0.410       | −0.091     | 0.261       | 0.013      | 0.715      | 0.042      | 0.313      |
| Time of using tablet (hour/day) | 1.179    | <0.001      | 0.905      | 0.002      | 0.034      | 0.660       | −0.053     | 0.514       | 0.029      | 0.468      | 0.047      | 0.260      |
| Time of using computer (hour/day) | 1.432    | 0.001       | 0.659      | 0.138      | 0.180      | 0.109       | 0.148      | 0.232       | −0.008     | 0.889      | −0.026     | 0.684      |
| Time of doing homework (hour/day) | 2.257    | <0.001      | 2.252      | <0.001     | −0.084     | 0.467       | −0.067     | 0.563       | −0.047     | 0.424      | −0.055     | 0.357      |
| Sleeping time (hour/day)      | −0.115   | 0.668       | −0.003     | 0.990      | 0.048      | 0.508       | 0.021      | 0.770       | −0.014     | 0.694      | −0.012     | 0.755      |
| NA                            |          |             |            |            |            |             |            |             |            |

**Different digital media experiences with OSDI, TBUT and CFSS**

Ordinal logistic regression analysis (table 5) was performed to assess the relationship between different digital devices and the diverse levels of OSDI in which children were divided into asymptomatic, mild, moderate and severe symptomatic groups according to the corresponding level of OSDI. The independent variables for the multivariable model included usage of television, smartphone, tablet and computer per day. Only two independent variables were found to have a statistically significant influence on the model: daily hours on smartphone and tablet. Students who used smartphones (p=0.001, OR=2.355) and tablets (p=0.045, OR=1.786) for more than 1 hour per day were more likely to have higher OSDI levels than students who used them for less or equal to 1 hour.

Furthermore, binary logistic regression analysis was used to evaluate the relationship between different digital media usage and different abnormal dry eye signs. Watching on smartphones (OR=1.459, 95% CI (1.00 to 2.13), p=0.050) and tablets (OR=1.587, 95% CI (1.03 to 2.46), p=0.038) for more than 1 hour per day was independently associated with ‘TBUT ≤5s’. Similarly, using tablets for more than 1 hour per day (OR=1.53, 95% CI (1.02 to 2.29), p=0.038) was independently associated with ‘CFSS ≥1’.

Table 6 lists the correlation coefficient between different digital media experiences and OSDI, TBUT and CFSS. OSDI was significantly positively related to the daily hours on smartphone (r=0.082, p<0.001) and tablet (r=0.064, p=0.001). There were positive correlations between TBUT and daily hours on television (r=0.050, p=0.010). No relationship was found between CFSS and different types of electronic devices.
DISCUSSION

Our study is the largest population-based study of DED in Chinese children documented so far. We highlighted the impact of using different types of electronic products for varying amounts of time every day on the ocular surface, and revealed that viewing a cell phone or tablet for an average of more than 1 hour per day for a year is associated with ‘definite DED’ and ‘symptomatic DED’. Moreover, among 2694 Chinese elementary school children aged 7–8 years old, the prevalence based on ‘symptomatic DED’ (an OSDI score ≥13) was 8.7% and the ‘definite DED’ (an OSDI score ≥13 and TBUT ≤5 s) prevalence rate was 5.5%. We have identified that previous literature often focused on one DED type and only reported a short-term ocular surface discomfort induced by media display usage, so the outcomes of this research may fill a gap in this study area.

Most important of all, in adults, visual display terminal (VDT) use has been reported to be accompanied by a reduction in blinking and an increase in interpalpebral ocular surface area, which can cause tear film instability and DED. In schoolchildren, the use of VDT has also increased among the growing amount of online study and changing ways of entertainment. Most previous case–control studies focused on the short-term ocular surface discomfort, visual discomfort and asthenopic symptoms with different digital displays. A crowdsourced cross-sectional study visualised the heterogeneous DED symptoms into seven distinct subgroups and revealed that participants in some clusters that observed shortened maximum blink interval with higher OSDI total score were partly due to overusage of digital media in the increasingly digitalised society. Considering the difference in viewing position, size, method and pattern of use between television, smartphone, tablet and computer, our study focused on the effects of long-term use of digital media on the ocular surface. Since clinical signs (TBUT and CFSS) are not significantly correlated with DED symptoms (OSDI scores) in children, which is consistent with the finding in adults, the risk factors for ‘definite DED’ and ‘symptomatic DED’ were investigated separately and innovatively. We have revealed that viewing a cell phone or tablet for an average of more than 1 hour per day over a year was associated with ‘definite DED’ and ‘symptomatic DED’. It was hypothesised that the short watching distance of smartphones and tablets exerts a more substantial influence on the symptoms and tear film stability than bigger size and longer watching distance of computers and TV, ultimately leading to ‘definite DED’. Meanwhile, smartphones and tablets are the smallest handheld devices compared with computers and TVs, and comprise a smaller display oriented in the vertical plane. Hence, symptoms may vary in people according to their usage. When we divided the children into different symptomatic groups, as mentioned above, we found that students who used smartphones and tablets for more than 1 hour per day were more likely to get higher OSDI levels, indicating that longer usage of these gadgets daily was directly related to the severity of dry eye symptoms.

| Variable                  | P value | OR  | 95% CI   |
|---------------------------|---------|-----|----------|
| Time of watching TV (hour/day) |         |     |          |
| ≤1                        | Ref     | Ref | NA       |
| >1                        | 0.986   | 0.996 | 0.671 to 1.479 |
| Time of using smartphone (hour/day) |         |     |          |
| ≤1                        | Ref     | Ref | NA       |
| >1                        | 0.001   | 2.355 | 1.440 to 3.853 |
| Time of using tablet (hour/day) |         |     |          |
| ≤1                        | Ref     | Ref | NA       |
| >1                        | 0.045   | 1.786 | 1.014 to 3.145 |
| Time of using computer (hour/day) |         |     |          |
| ≤1                        | Ref     | Ref | NA       |
| >1                        | 0.417   | 1.507 | 0.560 to 4.050 |

The dependent variable is different OSDI levels (divided into asymptomatic, mild, moderate and severe symptomatic group). NA, not applicable; OSDI, Ocular Surface Disease Index.

Table 6  Correlation between daily hours on different electronic devices with Ocular Surface Disease Index (OSDI), tear breakup time (TBUT) and corneal fluorescein staining scores (CFSS)

| Average daily hours on different electronic devices | OSDI r | P value | TBUT r | P value | CFSS r | P value |
|---------------------------------------------------|--------|---------|--------|---------|--------|---------|
| Television (hour/day)                             | 0.003  | 0.881   | 0.050  | 0.010   | −0.009 | 0.630   |
| Smartphone (hour/day)                             | 0.082  | <0.001  | 0.016  | 0.400   | 0.015  | 0.425   |
| Tablet (hour/day)                                 | 0.064  | 0.001   | −0.001 | 0.948   | 0.034  | 0.077   |
| Computer (hour/day)                               | 0.030  | 0.122   | 0.011  | 0.561   | 0.010  | 0.621   |

r, correlation coefficient.
The correlations between television/tablet usage with TBUT and CFSS revealed that when students rely on these technologies often, abnormal dry eye signs may ensue. Correlation coefficients between OSDI, TBUT and CFSS and different electronic devices were also reported, boosting the distinction of the ocular surface effects of different electronic devices. The daily hours on television being positively correlated with TBUT in our study might be inconsistent with previous studies, indicating the low reliability of judging children’s dry eye only according to TBUT fluctuation.

Second, although age was identified as a risk factor for DED in certain studies, a Japanese study revealed that younger individuals might be more susceptible to self-reported ocular symptoms than older individuals. Therefore, we highlighted that the prevalence of ‘symptomatic DED’ was 8.7% in elementary school children, which was similar to the findings of a Japanese report (6.7%) for elementary school children, but lower than those reported in junior high school (16.4%), senior high school (21%–24%) and younger individuals below 20 years old (76.44%) in previous studies. This finding suggests that the severity of DED symptoms increased with age in children and adolescents, which may be attributable to the increased usage of digital devices, as indicated in the TFOS DEWS II report. Moreover, the presence of the ocular surface signs should not be overlooked as some young children may not be able to describe symptoms subjectively, and considering the differences in ocular surface characteristics between Asians and Caucasians, the definition of ‘definite DED’ was devised based on symptoms and signs according to the consensus reported by the Asia Dry Eye Society. Despite numerous studies reporting the prevalence of DED based on symptoms and signs in adults, due to the lack of a ‘gold standard’ for the DED diagnosis, each study used varying criteria and reported various prevalence rates (8.7%–30.1%). A cross-sectional study published in 2017 among Shanghai University students reported a higher prevalence rate (10%) using the same DED definition.

Furthermore, more risk and protective factors have been identified. More than 1 hour per day on homework was also associated with ‘definite DED’ and ‘symptomatic DED’, highlighting that close observation and caution are required for the ocular surface health in children with heavy academic burden. AC was also significantly associated with ‘definite DED’ and ‘symptomatic DED’, indicating that close attention should be paid to the evaluation of ocular surface parameters in children with AC. Previous studies reported that inadequate refractive correction might be an actual risk factor for DED. Our results supported this assumption, showing that inadequate refractive correction was found in 2.04% of total students and to be associated with ‘definite DED’, revealing that inadequate refractive correction might be one cause of ocular surface impairment in Chinese students. However, more than 1 hour per day on outdoor activities was considered as a protective factor for ‘symptomatic DED’, which means that the number of hours spent outdoors is inversely proportional to eye strain and discomfort. Due to the limitation of children’s age, other risk factors suggested by previous study, such as female sex, current CL use and sleeping time, were not corroborated as DED risk factors in this study.

Strengths and limitations
This study updated the ocular surface health data in children and emphasised some long-term lifestyle habits, especially regarding the usage and dependence on digital display screens, may lead to occurrence of paediatric dry eye in eastern Chinese children. We also established a comprehensive definition of DED that included ‘definite DED’ and ‘symptomatic DED’ and its focus was the investigation of the prevalence and risk factors in both cases. Other benefits include its population-based design, large sample size (2694 primary school children between 7 and 8 years old) and high participating rates (>80%). However, our study has also encountered limitations. First, the prevalence estimate may be biased due to the uncooperative nature of young children, and lifestyles recalled by parents might be subject to recall bias. Second, due to the limited time available for ocular examinations during the field survey, not all ocular surface parameters were measured on our subjects. Third, the age range of our participants was restricted to subjects between 7 and 8 years old, which could only represent relatively younger children.

Thus, we would like to evaluate the prevalence and risk factors of dry eye in children of different ages and going through various learning stages. It is equally important to evaluate whether there would be changes in tear film stability after children improve their daily routine and eye care habits in future researches.

CONCLUSIONS
This large population-based study, which includes 2694 Chinese elementary school children aged 7–8 years old, investigates the prevalence of and risk factors for ‘definite DED’ and ‘symptomatic DED’. We innovatively discover that using smartphones or tablets for an average of more than 1 hour per day through the course of a year is associated with cases of definite and symptomatic DED. We have concluded that longer usage of these gadgets (smartphones and tablets) is also related to the severity of dry eye symptoms. Similarly, children who have been exposed to television or tablet screen may also present abnormal dry eye signs. The assessment of these risk factors for DED might help identify high-risk cases among children so they can be promptly evaluated and treated.

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Patient consent for publication Parental/guardian consent obtained.

Ethics approval This study was approved by the Ethics Committee of Nanjing Medical University (2017-SR-205) and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from the parents or legal guardians of all participating children. Oral assent was obtained from all children right before the examination.

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