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Low physical activity and higher use of screen devices are associated with myopia at the age of 16-17 years in the CCC2000 Eye Study

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ABSTRACT

Purpose: To determine the myopia prevalence in a Danish cohort aged 16-17 years and its relation to physical activity and use of screen-based electronic devices.

Methods: The Copenhagen Child Cohort 2000 Eye Study is a prospective, population-based, observational study. Information about use of screen devices and physical activity were obtained using questionnaires. Myopia was defined as non-cycloplegic subjective spherical equivalent refraction \( \leq -0.50 \) D in right eye.

Results: We included 1443 participants (45% boys) with a median age (± IQR) of 16.6 years (± 0.3). The prevalence of myopia was 25% (CI95% 23-28, n=360) with no differences between sexes (p=0.10).

The odds ratio (OR) for myopia was 0.57 (CI95% 0.42-0.76, p=0.0002) in participants physically active 3-6 hours/week (n=502) and 0.56 (CI95% 0.42-0.76, p=0.0002) if active > 6 hours/week (n=506), both compared with participants physically active < 3 hours/week (n=396).

The use of screen devices > 6 hours/day was associated with increased OR for myopia compared with screen device use < 2 hours/day in both weekdays (OR=1.95, CI95% 1.16-3.30, p=0.012) and weekends (OR=2.10, CI95% 1.17-3.77, p=0.013).

Conclusion: In this cohort of healthy 16-17-year-olds, lower physical activity and more use of screen devices contributed significantly to the observed 25% prevalence of myopia with a roughly doubled risk of having myopia if physically active < 3 hours/week or if using screen devices > 6 hours/day. Our results support physical activity being a protective factor and nearwork a risk factor for myopia in adolescents.

Key words: Myopia prevalence, physical activity, exercise, tablets, smartphones, adolescents, cohort study, mobile devices, near-sightedness

Introduction
Myopia prevalence is increasing globally, from 23% of the world’s population in 2000 to an expected 50% in 2050 (Holden et al. 2016), which is a matter of serious public health concern (WHO 2015). Myopia is more common in urban than in rural areas (Morgan et al. 2012) and it is associated with higher levels of education (Morgan & Rose 2005), especially observed in East Asia (Morgan et al. 2012). The most common studied behavioural determinants are physical activity, time spent outdoors, and time spent on near-work activities. Outdoor activity has consistently been found to prevent myopia (Xiong et al. 2017), whereas the effect of physical activity is more uncertain (Suhr Thykjaer et al. 2017). A detrimental effect of near-work activities has been suspected for centuries (de Jong 2018), but it has been surprisingly difficult to verify (Huang et al. 2015). This issue is of increasing interest because near-work has risen dramatically with the proliferation of screen-based electronic devices such as smartphones, tablets and computers. The purpose of this study was to determine the prevalence of myopia and its association with physical activity and the use of screen-based devices, in a cohort of adolescents.

**Methods**

**Study population**

The Copenhagen Child Cohort 2000 (CCC2000) is a prospective, population-based, observational study initiated in the year 2000 (Skovgaard et al. 2005). In brief, it comprises 6090 children born in the year 2000 in 16 municipalities of the defunct Copenhagen County in Denmark, a predominantly urban region. The CCC2000 Eye Study was appended in 2011 (Li et al. 2014; Li et al. 2015; Ashina et al. 2017; Malmqvist et al. 2017). A second round of eye examinations was made between August 20, 2016 and August 31, 2017 when the participants were aged 16-17 years and included 1445 participants. Two participants were excluded from present study due to incident eye disease other than myopia. All subjects and their parents or legal guardians gave their written informed consent. The protocol was in accordance with the Declaration of Helsinki and was assessed by the local medical ethics committee (protocol number 16023242).

**Procedures**

The participants were asked about their history of eye diseases and eye surgery and use of glasses and contact lenses. The refractive power of prescribed glasses was measured using an automated lensmeter (Nikon NL-2 automatic lensmeter; Nikon CO., Tokyo, Japan). If the participants used contact lenses or had not brought their glasses to the examination, the power was registered only when the participant knew its numerical dioptre values. Contact lenses were removed before the eye examination. All participants
underwent the same examination protocol regardless of prior use or non-use of glasses or contact lenses.

Non-cycloplegic subjective refractioning was performed using ETDRS charts (4-meter original series; Precision-Vision, La Salle, IL, USA) guided by an automated refractometer (Nidek AR-660A auto refractometer; NIDEK CO., LTD., Gamagori, Aichi 443-0038, Japan). The participants were asked to read as many letters as possible with their autorefractor correction. Then +0.50 D lenses were added consecutively until a significant blur occurred. Hereafter, -0.25 lenses were added until maximum visual acuity was achieved and denoted as the best corrected visual acuity (BCVA). Right and left eyes were tested separately. Myopia was defined when the subjective spherical equivalent refraction was ≤ -0.50 D.

We used an interferometric device (IOL-Master, version 3.01.0294; Carl Zeiss Meditec, La Jolla, CA, USA) to measure the axial length, corneal curvature and anterior chamber depth of the eye. Participants’ height was measured using a wall-mounted altimeter (Height Measuring Rod 5002.02; Soehnle Professional GmbH & Co., Backnang, Germany) and body weight using an electronic scale with a bio-impedance measurement device (TBF 300A, Tanita Europe BV, Amsterdam, The Netherlands).

Information about physical activity was obtained as part of an online questionnaire filled in by the participants no more than three months before the visit. The question (translated from Danish) sounded: “During the last year, how many hours of physical activity have you performed per week (including bicycling, brisk walks, any kind of sport or fitness, and physical education in school)?”. The predefined answers that were provided were “none”, “< 1 hour/week”, “1-2 hours/week”, “3-6 hours/week”, “7-14 hours/week” and “> 14 hours/week”. Information about the use of electronic screen-based devices was obtained as part of a questionnaire answered by the participants during the eye examination. The question (translated from Danish with appropriate bold and underlined text) sounded: “During the last two weeks, how many hours per day did you use a smartphone, tablet or computer? (Writing messages/mails, surfing the internet, watching movies or video-clips, using social media, performing school work, playing games, etc.)”. The response options were “< ½ hour/day”, “½-2 hours/day”, “2-4 hours/day”, “4-6 hours/day” and “> 6 hours/day”. The participants were asked to answer the latter question separately for weekdays and weekends. Data were missing for 8 participants regarding use of screen devices and for 39 participants regarding physical activity.

Statistics

The SAS® Enterprise Guide software package (version 7.2; SAS Institute, Cary, NC, USA) was used in all statistical analyses. Student’s t-test was used when analysing continuous data except in the case of age, weight and body mass index where the Wilcoxon rank sum test was used due to non-normal distribution of data. The chi-square test was used to compare sexual distribution and level of physical activity between

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participants with and without myopia. Fischer's exact test was used to compare the use of screen devices.

We used logistic regression models to calculate the odds for myopia in the different subgroups.

Spherical equivalent refraction was calculated by adding half of the negative cylinder refraction to the spherical refraction and mean corneal curvature as the average of the steepest and the flattest corneal meridian. Body mass index was defined as body weight in kilograms divided by the squared body height in metres.

To achieve better balance between the number of observations per category in the logistic regression analysis, we merged the physical activity categories into three, namely “< 3 hours/week”, “3-6 hours/week”, “> 6 hours/week” and the screen device categories into four, namely “< 2 hours/day”, “2-4 hours/day”, “4-6 hours/day” and “> 6 hours/day”.

Categorical data from the questionnaire were transformed into ordinal data and Spearman’s rank correlation was used to assess the correlation between the use of screen devices in weekdays and weekends, in 5 categories ranging from < 30 min/day to > 6 hours/day, and their correlation to physical activity, in 5 categories ranging from < 1 hour/week to > 14 hours/week.

The level of statistical significance was set at $p < 0.05$.

Results

The analysis comprised 1443 subjects (45% boys) with a median (± IQR) age of 16.6 ± 0.3 years (Table 1).

Subjective spherical equivalent refraction was comparable between right and left eyes (Fig. 1, Table 2).

Myopia ≤ -0.50 D was found in 25% (CI95% 23 to 28, n=360) of right eyes and did not differ between sexes ($p=0.10$). In 14% (n=202), the spherical equivalent refraction was ≤ 1.00 D and in 8% (n=117), it was < -1.50 D (Fig. 1, Table 2).

Compared with participants who were physically active < 3 hours/week, the odds ratio (OR) for myopia (≤ -0.50 D) in the right eye was 0.57 (CI95% 0.42 to 0.76, $p=0.0002$) for participants who were physically active 3-6 hours/week and 0.56 (CI95% 0.42 to 0.76, $p=0.0002$) for participants who were physically active > 6 hours/week, (adjusted for sex and age; Table 3a). The association remained significant when also adjusting for weight, height, and time spent using screen devices (Table 3a) and when defining myopia as ≤ -1.00 D (Table 3b).
Compared with weekday use of devices < 2 hours/day and adjusted for sex and age, the OR for myopia was 1.85 (CI95% 1.08 to 3.15, p=0.024) for use of devices 2-4 hours/day and 1.95 (CI95% 1.16 to 3.30, 0.012) for use > 6 hours/day, with a similar tendency when using devices 4-6 hours/week (OR=1.66, CI95% 0.99 to 2.81, p=0.06; Table 3a). Compared with weekend use of devices < 2 hours/day, the sex and age-adjusted OR for myopia increased by 2.10 (CI95% 1.17 to 3.77, p=0.013) for use of devices > 6 hours/day, with similar tendencies when using devices 2-4 hours/week (OR=1.77, CI95% 0.96 to 3.26, p=0.07) and 4-6 hours/week (OR=1.66, CI95% 0.92 to 3.00, p=0.09; Table 3a). Further adjusting for weight, height, and physical activity did not alter the significance of the associations (Table 3a). The association was not present when defining myopia as ≤ -1.00 D (Table 3b).

The correlation between screen device use during weekdays and weekends was 0.57 (CI95% 0.54 to 0.61). The correlations between physical activity and use of screen devices during weekdays and weekends, were -0.09 (CI95% -0.14 to -0.03) and -0.13 (CI95% -0.18 to -0.07), respectively.

We found no associations between age, sex, height, weight or body mass index and myopia (Table 1). We found no interactions between sex and any of the tested variables.

Discussion

In the population-based CCC2000 birth cohort lower physical activity and more use of screen-based electronic devices contributed to the observed 25% prevalence of myopia at the age of 16-17 years. Being physically active more than three hours per week was associated with a 40% reduction in the odds for myopia and the use of screen devices more than six hours a day approximately doubled the odds of having myopia ≤ -0.50 D.
The observed 25% prevalence of myopia, defined as non-cycloplegic spherical equivalent ≤ -0.50 D, was higher than the 18% reported in a recent Danish study of 307 schoolchildren aged 14-17 years (Lundberg et al. 2018). The difference could be caused by the slightly younger age of the subjects (mean age 15.4) and the use of cycloplegia in their study. Non-cycloplegic subjective refractioning has been shown to overestimate negative refraction compared with cycloplegic autorefraction in children and young adults, though the bias is worse in younger participants and when assessing hyperopia (Choong et al. 2006; Funarunart et al. 2009; Hashemi et al. 2016; Jan et al. 2018). Older studies from Denmark defined myopia as < -1.50 D (Tscherning 1882; Goldschmidt 1968; Fledelius 1983; Jacobsen et al. 2007), a definition that yields a prevalence of 8% in the present study, which is nearly the same as in other studies made in Denmark during the last 135 years, namely 8% in 7523 male conscripts in 1882 (Tscherning 1882), 9% in 3651 male conscripts in 1964 (Goldschmidt 1968), 10% in 414 participants of both sexes aged 16 to 25 years in 1982 (Fledelius 1983) and 8% in 4681 male conscripts in 2004 (Jacobsen et al. 2007). This historical stability is in striking contrast to the development in East Asia. A recent study from China found an increase in the prevalence of myopia (≤ -0.50 D) among 14- to 16-year old high-school children from 56% to 65% over a single decade (Li et al. 2017) and a study of 17-year olds from Australia reported a prevalence of myopia of 59% among subjects with East Asian ethnicity while the prevalence among subjects of European ethnicity was 18% (French et al. 2013). While the lack of cycloplegia may had led to an overestimation of the myopia prevalence in our study, it is highly unlikely that the prevalence is above 25% and it thus remains in line with other European studies of comparable age groups (Vannas et al. 2003; Czepita et al. 2007; McCullough et al. 2016; Hagen et al. 2018). The reasons for these differences between European and East Asian populations are not fully understood. The variation in known genetic risk factors is minimal between the populations (Verhoeven et al. 2013) why the focus is currently on differences in environmental factors such as educational load and time spent outdoor (Morgan et al. 2018).

We found a lower prevalence of myopia among participants who were physically active > 3 hours per week. This corresponds to a study from Northern Ireland based on 661 children aged 12 to 13 years where physical activity > 3 hours per week reduced the odds of having myopia (OR=0.46) (O'Donoghue et al. 2015). In present study, being active 3-6 hours per week and > 6 hours equally reduced the risk for myopia. The reason that we did not find a dose response effect may be that there is no such effect and being physically active > 6 hours per week does not result in further decrease in the risk of myopia than being active 3-6 hours per week. Another explanation may be that our method of registering the activity level by self-reporting is insufficient to show a potential dose-response effect. Our finding that physically active subjects were less likely to have myopia than those who were less active supports findings from a range of previous studies. A prospective study of 156 medical students from Denmark found less myopic refractive...
development when subjects were more physically active (+0.175 D per hour of daily physical activity) (Jacobsen et al. 2008). Another study of 2542 children from the British ALSPAC cohort found that both higher general physical activity (hazard ratio=0.88) and more time spent on moderate to vigorous physical activity (hazard ratio=0.87) were associated with a reduced incidence of myopia (Guggenheim et al. 2012). Additionally, two cross-sectional studies of 1777 students from Jordan (aged 12-17 years) (Khader et al. 2006) and 366 children from the United States (mean age=13.7) (Mutti et al. 2002), respectively, showed that the odds for having myopia were reduced by 10% for every additional hour of sports activity per week.

It has been debated whether physical activity is simply a surrogate measurement of outdoor activity and daylight exposure (Suhr Thykjaer et al. 2017). Thus, several studies of outdoor exposure conclude that it is time spent outdoors rather than physical activity that affects myopia development (Rose et al. 2006; Rose et al. 2008; Dirani et al. 2009; Guggenheim et al. 2012; Read et al. 2014). Since the present study did not collect information about neither the type of physical activity nor its location indoors/outdoors we cannot offer any conclusions about this question. However, patterns of physical activity in adolescents in Denmark have been described in a recent report by “The Danish Institute for Sports Studies” (DTU 2015). The most common locations for physical activity among 16-19-year-olds in Denmark are in fitness centres (used by 50%), open-air nature (used by 40%) and streets (used by 34%). Other common locations include indoor sports centres (32%) and gym halls (29%), football courts (27%) and indoors or outdoors at home (27%). Also, 14% uses other outdoor facilities (such as courts for tennis, golf, athletics and beach volleyball), 11% use the water or ocean and 10% use parks. Another report shows that 43% of 16-17-year-olds ride a bike (33%) or walk (10%) to and from school while 12% are driven to school by a parent and 39% use public transportation (Pilgaard & Rask 2016). Consequently, a substantial amount of physical activities takes place during time spent outdoors, whence it is reasonable to guess, but by no means proved, that in our study population a considerable fraction of the time spent outdoors involved physical activity.

The daily use of screen-based devices during weekdays and weekends was correlated and we found a lower prevalence of myopia among participants who used these devices less than two hours a day. This association was remarkably unaffected by how physically active the participants were. While more time spent on near-work activities in general seem to be associated with myopia (Huang et al. 2015) an independent role of computers and electronic gadgets is still controversial. The association between myopia and the use of smartphones and tablets has not been studied before but Khader and colleagues (Khader et al. 2006) found an association between existing myopia and computer use (OR=1.16 per additional hour). Another study of 1318 children from the United States found that myopic children used more time on computers and video games compared with emmetropic children (Jones-Jordan et al. 2011).
Conversely, Mutti and colleagues found no such association between myopia and video games/computer use (Mutti et al. 2002) and no studies have been able to show an effect on incident myopia or myopia progression (Saw et al. 2006; Jones et al. 2007; Jacobsen et al. 2008; Jones-Jordan et al. 2012; Wu et al. 2013). Additionally, the association found in the present study was not significant when defining myopia as $\leq -1.00$ D. This inconsistency adds to the intriguing issue of near-work in myopia development and progression and the role of factors such as reading distance and reading intensity (Ip et al. 2008) could be of greater importance than the total amount of time spent on near work. As the current knowledge mainly relies on questionnaires, future interventive studies are desirable to confirm a potential effect.

The present study covered a large population-based cohort. Major limitations include the non-use of cycloplegia and the lack of collection of outdoor activity data. Thus, we cannot separate the effects of being physically active and being outside in daylight. Additionally, we did not collect information about other near-work activities or the participants reading distance and reading intensity in relation to the use of screen devices which may influence their effect on myopia. Finally, assessment of physical activity by the use of questionnaires can be subject to recall bias, overestimation of physical activity and underestimation of sedentary behaviour (Shephard 2003). Given the cross-sectional design of the study, no conclusion on causality can be made.

In conclusion, we found a prevalence of myopia $\leq -0.50$ D of 25% among participants aged 16 to 17 years in an urban setting in Denmark. In contrast to East Asia, the myopia prevalence among Danish adolescents has been largely unchanged for more than one hundred years despite the massive increase in the use of handheld screen devices among the younger generations within the last decades. We found that increased use of screen devices was associated with increased odds for myopia $\leq -0.50$ D but not for myopia $\leq -1.00$ D. Being physically active three hours or more per week was associated with a marked decrease of the odds for myopia $\leq -0.50$ D as well as $\leq -1.00$ D emphasizing the importance of promoting an active lifestyle early in life.

Acknowledgment

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Disclosures: None.

References:


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<tr>
<th>Parameter</th>
<th>All participants</th>
<th>Subjects with myopia, n=360</th>
<th>Subjects without myopia, n=1083</th>
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<td>Age, median (IQR), years</td>
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<td>16.6 (0.3)</td>
<td>16.6 (0.3)</td>
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<td>89 (4)</td>
<td>91 (5)</td>
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<td>-0.125 (0.5)</td>
<td>-1.0 (1.375)</td>
<td>0.0 (0.375)</td>
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<td>Boys, No. (%)</td>
<td>643 (45)</td>
<td>147 (41)</td>
<td>496 (46)</td>
<td>0.10</td>
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<td>Axial length, mean (SD), mm</td>
<td>23.5 (0.9)</td>
<td>24.1 (1.0)</td>
<td>23.3 (0.7)</td>
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<td>Anterior chamber depth, mean (SD), mm</td>
<td>3.52 (0.3)</td>
<td>3.63 (0.3)</td>
<td>3.48 (0.2)</td>
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<td>Corneal curvature, mean (SD), mm</td>
<td>7.81 (0.3)</td>
<td>7.79 (0.3)</td>
<td>7.82 (0.3)</td>
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<td>Height, mean (SD), cm</td>
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<td></td>
<td></td>
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<tr>
<td>Boys</td>
<td>179 (7)</td>
<td>178 (7)</td>
<td>180 (7)</td>
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<tr>
<td>Girls</td>
<td>167 (6)</td>
<td>167 (7)</td>
<td>167 (6)</td>
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<td>Weight, median (IQR), kg</td>
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<td>60.0 (13)</td>
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<td>0.70</td>
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<tr>
<td>Girls</td>
<td>21.5 (4)</td>
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<td>21.5 (4)</td>
<td>0.48</td>
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<td>Weekly physical activity, No. (%)</td>
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<td>n = 352</td>
<td>n = 1052</td>
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<td>13 (4)</td>
<td>20 (2)</td>
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<tr>
<td>&lt; 1 hour/week</td>
<td>112 (8)</td>
<td>35 (10)</td>
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<td>1 - 2 hours/week</td>
<td>251 (18)</td>
<td>84 (24)</td>
<td>167 (16)</td>
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<td>3 - 6 hours/week</td>
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<td>111 (32)</td>
<td>391 (37)</td>
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<td>7 - 14 hours/week</td>
<td>387 (28)</td>
<td>93 (26)</td>
<td>294 (28)</td>
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<td>119 (8)</td>
<td>16 (5)</td>
<td>103 (10)</td>
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<td>Screen-based electronic devices, No. (%)</td>
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<td>n = 357</td>
<td>n = 1078</td>
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<td>Weekdays</td>
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<td>&lt; 30 minutes/day</td>
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<td>½ - 2 hours/day</td>
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<td>18 (5)</td>
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<td>&gt; 6 hours/day</td>
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<td>----------</td>
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<td>&lt; 30 minutes/day</td>
<td>4</td>
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<td>½ - 2 hours/day</td>
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<td>482</td>
<td>(34)</td>
<td>113 (32)</td>
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<td>&gt; 6 hours/day</td>
<td>561</td>
<td>(39)</td>
<td>157 (44)</td>
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</table>

Abbreviations: IQR = interquartile range, BCVA = best-corrected visual acuity, ETDRS = Early Treatment Diabetic Retinopathy Study, SD = standard deviation
Table 2. Prevalence of negative refractive errors among 1443 adolescents of 16 to 17 years of age

<table>
<thead>
<tr>
<th>Myopia definition</th>
<th>Right eyes</th>
<th>Left eyes</th>
<th>Both eyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ -0.25 D, n (%)</td>
<td>554 (38)</td>
<td>557 (39)</td>
<td>431 (30)</td>
</tr>
<tr>
<td>≤ -0.50 D, n (%)</td>
<td>360 (25)</td>
<td>349 (24)</td>
<td>276 (19)</td>
</tr>
<tr>
<td>≤ -0.75 D, n (%)</td>
<td>251 (17)</td>
<td>253 (18)</td>
<td>215 (15)</td>
</tr>
<tr>
<td>≤ -1.00 D, n (%)</td>
<td>202 (14)</td>
<td>188 (13)</td>
<td>165 (11)</td>
</tr>
<tr>
<td>≤ -1.25 D, n (%)</td>
<td>158 (11)</td>
<td>159 (11)</td>
<td>135 (9)</td>
</tr>
<tr>
<td>≤ -1.50 D, n (%)</td>
<td>128 (9)</td>
<td>134 (9)</td>
<td>111 (8)</td>
</tr>
<tr>
<td>&lt; -1.50 D, n (%)</td>
<td>117 (8)</td>
<td>124 (9)</td>
<td>102 (7)</td>
</tr>
</tbody>
</table>
Fig. 1. Distribution of the subjective spherical equivalent refraction in a cohort of 16-17-year old subjects.