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Smartphone use as a possible risk factor for myopia

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Clinical relevance: This study demonstrates an association between myopia and smartphone data usage. Youths now spend more time participating in near tasks as a result of smartphone usage. This poses an additional risk factor for myopia development/progression and is an important research question in relation to potential myopia management strategies.

Background: Children are now exposed to another possible environmental risk factor for myopia – smartphones. This study investigates the amount of time students spend on their smartphones and their patterns of smartphone usage from a myopia perspective.

Methods: Primary, secondary and tertiary level students completed a questionnaire exploring patterns of smartphone usage and assessing their attitudes toward potential myopia risk factors. Device-recorded data usage over an extended period was quantified as the primary and objective indicator of phone use. Average daily time spent using a smartphone was also quantified by self-reported estimates. Refractive status was verified by an optometrist.

Results: Smartphone ownership among the 418 students invited to participate was over 99 per cent. Average daily smartphone data and time usage was 800.37 ± 1,299.88 MB and 265.16 ± 168.02 minutes respectively. Myopic students used almost double the amount of smartphone data at 1,130.71 ± 1,748.14 MB per day compared to non-myopes at 613.63 ± 902.15 MB ($p = 0.001$). Smartphone time usage was not significantly different ($p = 0.09$, 12 per cent higher among myopes). Multinomial logistic regression revealed that myopic refractive error was statistically significantly associated with increasing daily smartphone data usage (odds ratio 1.08, 95% CI 1.03–1.14) as well as increasing age (odds ratio 1.09, 95% CI 1.02–1.17) and number of myopic parents (odds ratio 1.55, 95% CI 1.06–2.3). Seventy-three per cent of students believed that digital technology may adversely affect their eyes.

Conclusion: This study demonstrates an association between myopia and smartphone data usage. Given the serious nature of the ocular health risks associated with myopia, our findings indicate that this relationship merits more detailed investigation.

Key words: lifestyle, myopia, myopia prevention, risk factors, smartphones

Myopia is predicted to affect almost five billion people worldwide by 2050,[1] and is a global public health concern with significant social, educational, and economic consequences.[2] The onset of myopia has also shifted to a younger age,[3] which is a concern, as younger children exhibit more rapid myopia progression[4] and are more likely to reach higher levels of myopia. This can substantially increase the risk of developing sight-threatening conditions including myopic maculopathy, glaucoma, cataract and retinal detachment in later life.[5]

The aetiology of myopia is multifactorial, involving interplay between genetic environmental and behavioural factors, with decreased time outdoors,[6] urbanisation,[7] disturbed/delayed sleep,[8,9] increased time spent in education[10] and time spent reading continuously or in long periods of close work all cited as possible influences.[11]

Children and young adults are now exposed to another possible environmental risk factor for myopia – digital devices.[12] Smartphones, iPads, tablets and computers are used at a very early age in both home and school environments.[13] Children are the fastest growing population of smartphone users,[14] with 95 per cent of American teenagers reporting ownership of or access to a smartphone in 2018.[15] Smartphones are now the most used device for internet access on a daily basis by 9–16-year-olds in Ireland,[16] while 85 per cent of young people in the UK (aged 12–15) use a smartphone daily.[17]

Several studies have identified computer usage as a risk factor for myopia.[18–23] One study in particular, found myopia was associated with a closer computer screen working distance.[20] The working distance adopted by smartphone users is typically even closer than for computer screens.[24] It is conceivable, therefore, that increased and continuous exposure to a smartphone screen might represent a plausible risk factor for the development or progression of myopia, especially in younger age groups.

However, there is a scarcity of published literature investigating the relationship between smartphone use and myopia. Recent studies that have addressed the ocular impact of smartphone use have focused on self-reported estimates of time spent on a smartphone,[25–28] even though self-reported smartphone assessments have been shown to perform poorly when attempting to predict objective smartphone behaviours.[29]

This study was designed to investigate self-reported and device-tracked smartphone usage among children and young adults to determine whether any association exists with refractive status. Furthermore, the attitudes of students to mobile phones and digital technology as a risk factor for myopia were also explored.

Methods

Participants

Students across the spectrum of primary school (kindergarten to grade 6), secondary school (corresponding to grades 7–12) and tertiary (or university level) education settings were invited to participate in the study between January and March 2018. This was facilitated by an 'invitation to participate' email request sent to university staff via university administrators and to schools in the Republic of Ireland directly by the study investigator. The study investigator visited participating classrooms and potential participants were provided with a questionnaire. The study investigator explained the instructions on the questionnaire carefully with each class, and any questions were answered. For participants aged 16 and over, a consent form was signed and the questionnaires were completed instantly and collected by the study investigator. Students under the age of 16 and any subject over 16 who did not have their phone present in the classroom completed the questionnaire for homework along with the parental consent form (where applicable), and returned it to their teacher the following day. Completed forms were collected one week after distribution. Schools were contacted the day before the study investigator's return, to remind students to return their questionnaires if they had not done so. All students present on the day of the initial investigator visit agreed to participate in the study.

Study conduct

As the study was performed in a classroom rather than a clinical setting, a simple optometrist-led method was used to separate myopes from non-myopes. Prior to the study investigator visit, participants (or parents) were requested to bring a copy or photograph of their glasses or contact lens prescription to school, which was documented by the investigator. The investigator, a qualified optometrist, confirmed refractive status (including for those without a written prescription) by questioning student's use of their spectacle/contact lens prescription, their unaided signs and symptoms and by examining the students' spectacles to determine if lenses were convex (magnifying and hence hyperopic) or concave (minifying and hence myopic).

Questionnaire

An initial draft questionnaire was constructed and subsequently analysed by an external reviewer with expertise in questionnaire design. The questionnaire was pilot-tested on five people (two primary school students, two secondary school students and one university student), after which it was edited to remove leading or confusing questions. For Android users, smartphone data usage was queried by going into Settings > Data Usage > Mobile Data Usage as well as Settings > Data Usage > WI-FI Data Usage. For iPhone users, smartphone data usage was found via Settings > Mobile Data > Data Usage in Current Period, as well as Settings > Mobile Data > WI-FI Data Usage. Participants were asked to record the time period for data usage based on their current usage period (for Android users) or date of last reset (for iPhone users). These values are available within the phone settings and indicate the date from which the phone has been logging cellular data usage.

Average daily data usage was calculated by dividing the number of days from the last data reset by the amount of data used. Students were also asked to record the three applications (apps) that used the most data. Smartphone usage was also assessed by self-report. Participants were asked to estimate how much time they spend on average per day using their phone, the longest period of time spent on their phone at any one period in a week and how long they spend looking at their phone after going to bed. Nine tick box questions were used to capture participant demographics, record participant and self-reported parental myopia status, explore patterns of smartphone use (for example, whether used to read or watch TV programs, use for social media, internet and so on), quantify how often the phone was used after going to bed and to determine if participants thought the use of a phone screen impacted their eyes. An open-ended question probed participants' thoughts on the potential impact of the screen on their eyes. Parents were asked to assist in answering the questionnaire for participants under 16 years old.

Data analysis

Questionnaires were anonymous; participants were assured that all individual results would be kept strictly confidential. Participation in the study was voluntary. The study was approved by the Research Ethics Committee at Technological University Dublin. All data was collected between January and March 2018. The data collected was analysed on the statistical package for social sciences (IBM SPSS Statistics for Windows, Version 22.0; IBM, Armonk, NY, USA) and R version 3.2.2.in RStudio (RStudio, Inc., Boston, MA, USA). The Kolmogorov–Smirnov test for normality determined the smartphone usage data was not normally distributed. A Box–Cox transformation was therefore used to normalise smartphone data usage and time usage to facilitate parametric analysis. Non-parametric tests were used and the median and confidence intervals were reported where appropriate. The results were analysed using descriptive statistics and inferential statistics including Spearman's rank order correlation, chi-squared tests of independence, Kruskal–Wallis and Mann–Whitney U-tests. A statistical significance level of $p < 0.05$ was adopted throughout the analysis.

Results

Demographics

Three of the 418 (< one per cent) students initially invited to participate in the study did not own a smartphone (but used their parent's smartphone) and were excluded as their personal data usage could not be identified. Four hundred and two participants (96 per cent) aged between 10–33 years provided informed consent and completed the questionnaire (54 per cent, 216/402 female; 45 per cent, 181/397 male; one per cent, 5/402 not stated). The mean age was 16.77 (standard deviation [or ±] 4.4) years and 34 per cent (138/402) of participants wore glasses/contact lenses for myopia. The mean age at which myopic participants were first prescribed glasses was 11 years (range 3–19). There was some minor loss of data on

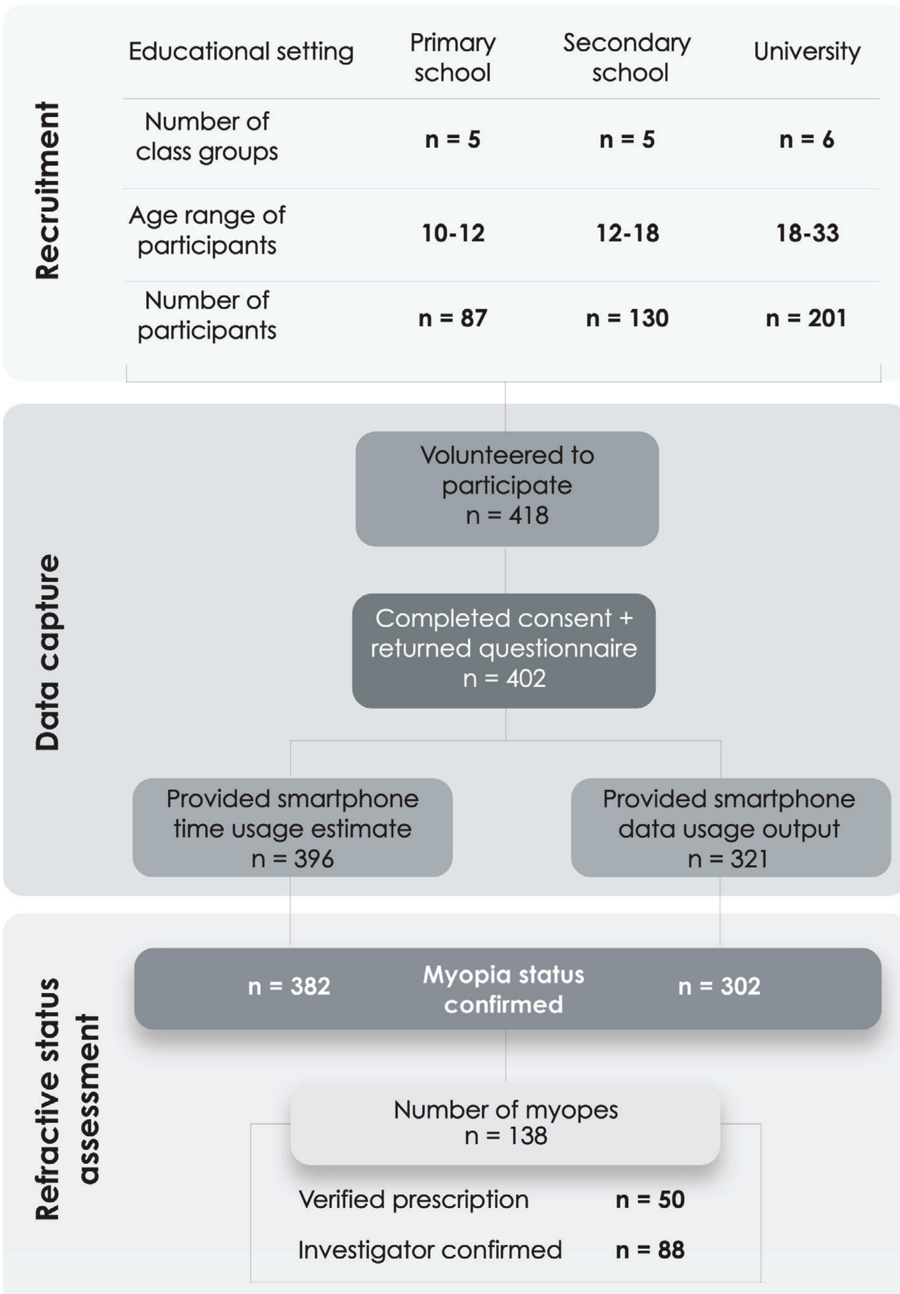

Figure 1. Participant recruitment, data capture and refractive status confirmation flowchart

specific questions due to incomplete responses or inability to confirm refractive status (spectacles or spectacle/contact lens prescription not provided by six participants). A detailed description of the recruitment setting, data capture and refractive status confirmation of all participants is provided in Figure 1, while participant demographics, behaviours and beliefs according to refractive status are provided in Table 1.

Smartphone usage

Students used an average of 873 ± 1,038 MB of data per day and spent an average of four hours and 32 ± 169 minutes per day on their phone. The longest period students reported spending on their phone at any one period in a week was an average of three hours 28 ± 188 minutes. The mean period since smartphone data was last reset was 215 ± 320 days. Data usage among myopic students was statistically significantly higher (84 per cent higher, p = 0.001) than non-myopes (Table 1). Self-reported smartphone time usage was not statistically significantly (p = 0.09) different between myopes and non-myopes (12 per cent higher self-reported use among myopes, Table 1).

Spearman's correlation revealed daily data usage (r = 0.14, df = 311, p = 0.01) and daily time spent on a smartphone (r = 0.04, df = 311, p = 0.41) was positively correlated with age. Simple linear regression analysis was used to test the relationship between Box–Cox normalised daily data usage and daily time spent on the phone. The results of the regression indicated three per cent of the variance could be explained by the model (daily data usage versus daily time) (R^2 = 0.033, $F_{[1,302]}$ = 10.2, p < 0.002).

The variation of data usage and time spent on a phone as a function of age/educational level is shown in Figure 2. The distribution of smartphone usage, particularly data usage, was positively skewed in both refractive groups. Non-parametric analysis (Mann–Whitney U-test) for each educational level showed a significant difference in daily data usage between myopic and non-myopic university students (p = 0.02) and a significant difference in daily time on phone between myopic and non-myopic primary school students (p = 0.02). Other comparisons were not significant. Log transformation of the usage data still resulted in a small amount of negative skew, as shown in the box-and-whisker plots in Figure 2. Subsequent parametric analysis on smartphone data usage was therefore performed following normalisation using a Box–Cox trans formation.

Eighty-four per cent (342/406) of students reported using their phone in bed. Spearman's correlation revealed age and time spent on a phone in bed were inversely correlated (ρ [323] = –0.25, p = 0.0001), with younger participants spending more time on a smartphone in bed compared to older students.

For most participants (72 per cent; 301/418), the main purpose of their smartphone was to use social media apps that involve screen interaction. Snapchat, Instagram and Facebook were the most used apps across all age groups and refractive error profiles. Spotify, podcasts and music applications that require less visual interaction by users were the most used applications by only four participants in the study.

	Myopes	Non-myopes	p-value
Demographics			
Age (mean)	18 ± 4 (9.33)	16 ± 5 (10.40)	**0.002**
Male	38% (48/128)	48% (124/257)	0.058†
Proportion of myopic parents			
No myopic parents	40% (55/137)	56% (143/257)	0.11†
One myopic parent	45% (61/137)	36% (92/257)	
Two myopic parents	15% (21/137)	9% (24/257)	
Smartphone behaviour			
Data usage per day (MB)	1,131 ± 1,748 (0.36–10,534)	614 ± 902 (0–6,000)	**0.001**
Time on phone per day (minutes)§	288 ± 174 (10–1,080)	258 ± 163 (5–785)	0.09
Phone in bed every night	64% (86/134)	61% (159/259)	0.72‡
Usage time in bed (minutes)	67 ± 68 (0–455)	71 ± 104 (1–1,335)	0.65
Smartphone-related beliefs			
Belief screens may affect eyes	84% (112/134)	68% (175/259)	**0.001**
Belief screens may cause myopia	31% (19/127)	25% (61/246)	0.223

Bold value indicates statistically significant results. Results indicated as mean ± standard deviation (range). p-values calculated using the Mann–Whitney U-test or, where otherwise indicated, using chi-squared (†) and Kruskal–Wallis H (‡) tests.
§Self-reported.

Table 1. Participant demographics, smartphone behaviour and related beliefs according to refractive status

Parent myopia status

Myopic participants with one (p = 0.01) and two (p = 0.04) myopic parents were first prescribed glasses for myopia at a younger age compared to myopic participants with no parental history of myopia.

Gender

A chi-squared test of independence revealed myopia status was not statistically significantly dependent on gender (χ^2 [1] = 3.57, p = 0.06).

Beliefs regarding digital technology and eye health

Overall 73 per cent (296/406) of students believed that digital technology may adversely affect their eyes, which was inversely correlated with age (ρ [402] = −0.15, p = 0.003). This belief was expressed statistically significantly more often by myopes (84 per cent; 112/134) than non-myopes (68 per cent; 175/259) (p = 0.001). Participants regarded screen usage as a cause of various symptoms including eye strain (29 per cent; 111/386), dry eyes (67 per cent; 28/386), headaches (five per cent; 18/385), and difficulty reading (two per cent; 9/383). A similar proportion of myopes (31 per cent; 39/127) and non-myopes (25 per cent; 61/246) expressed an opinion that a link existed between myopia and increased time spent looking at a screen (p = 0.22).

The above factors (that is, refractive status, phone usage, age, gender, number of myopic parents, and beliefs) were incorporated into a multinomial logistic regression model and revealed that myopic refractive error status was statistically significantly associated with increasing Box–Cox transformed daily smartphone data usage (p = 0.002), as well as increasing age (p = 0.01) and number of myopic parents (p = 0.008) (Table 2). A similar multinomial logistic regression revealed that myopic refractive error status was statistically significantly associated with Box–Cox transformed daily time spent on mobile phones (p = 0.04) as well as increasing age (p < 0.001), and number of myopic parents (p = 0.03, Table 3).

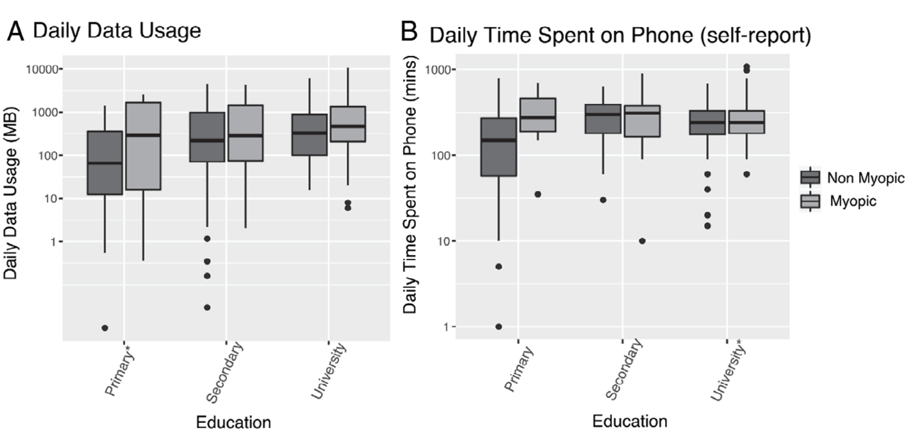

Figure 2. Daily smartphone data usage (MB) and daily self-reported smartphone usage time (minutes) according to education level for both myopic and non-myopic participants. A significant difference was found in daily data usage between myopic and non-myopic university students (p = 0.02, Mann–Whitney U-test) and in daily time on phone between myopic and non-myopic primary school students (p = 0.02, Mann–Whitney U-test).

Discussion

This study found an association between increased smartphone data usage and myopia with myopic participants using almost double the amount of data on a daily basis

Independent variable	B	SE(B)	z-value	Prob	Odds	Odds confidence intervals
Box–Cox daily data usage	0.08068	0.02583	3.123	0.002	1.08	(1.031–1.142)
Age	0.08708	0.03541	2.460	0.014	1.09	(1.02–1.17)
Number of myopic parents	0.44240	0.19709	2.245	0.008	1.55	(1.06–2.301)
Technology beliefs†	0.4448	0.31001	1.434	0.151	1.55	(1.001–3.301)
Gender	0.10949	0.28154	0.389	0.697	1.12	(0.644–1.94)

†Technology beliefs = belief that technology negatively impacts eyes.

Table 2. Summary of logistic regression analysis for variables predicting myopic status by Box–Cox of daily data usage (MB), age, parental myopia, a belief that technology can negatively impact eyes and gender for n = 286

Independent variable	B	SE(B)	z-value	Prob	Odds	Odds confidence intervals
Box–Cox daily time usage	0.02585	0.01241	2.084	0.0372	1.026	(1.001–1.051)
Age	0.13115	0.03069	4.273	< 0.001	1.14	(1.076–1.21)
Number of myopic parents	0.39767	0.17823	2.231	0.025	1.488	(1.05–2.116)
Technology beliefs†	0.53595	0.29441	1.820	0.0687	1.709	(0.97–3.092)
Gender	−0.4620	9.25381	−0.182	0.856	0.954	(0.579–1.57)

†Technology beliefs = belief that technology negatively impacts eyes.

Table 3. Summary of logistic regression analysis for variables predicting myopic status by Box–Cox of daily time spent on a smartphone (minutes), age, parental myopia, a belief that technology can negatively impact eyes and gender for n = 364

compared to those without myopia. This association remained significant even after statistical correction for possible confounders such as variation in data usage with age, number of myopic parents, gender and beliefs regarding technology that may influence smartphone usage patterns.

The lifestyle habits of children and teenagers today have undeniably changed with advancements in technology and while the prevalence of myopia has been increasing for decades, the increased level of near visual stimulation from smartphones may pose an additional independent risk for myopia. Smartphones differ from traditional reading in various aspects such as wavelength, distance from the eye, size, contrast, resolution, temporal properties and spectral composition, all of which merit investigation. Aside from this, children and adolescents now spend more than ever using a smartphone that demands proximal attention, which may compete with other more protective activities such as time outdoors.[6,13] The time (self-reported) devoted by children to smartphone use alone in the current study, excluding all other proximal tasks, is close to double that observed for all near work activities outside school hours in a study from Singapore (four hours 32 minutes compared to two hours 42 minutes per day)[30] and in a US study (four hours 32 minutes compared to two hours 18 minutes).[31] Moreover, smartphone ownership has increased dramatically among younger age groups in both advanced and emerging economies,[32] with over 99 per cent of students in the current study owning a smartphone and younger participants spending more time on a smartphone in bed compared to older students. Our findings indicate that children and adolescents are now spending substantially more time focusing on proximal tasks compared to that observed in studies conducted in the early and pre-smartphone era.[11,31]

In 2001, before the advent of smartphones, Saw et al. reported myopic children spent 40 minutes more than non-myopic participants participating in total near work activities daily.[30] Mutti et al. also reported myopes spent an additional 42 minutes per day on the computer, studying and reading compared to non-myopes.[31] This is similar to the additional 32 minutes spent by myopes using their smartphones compared to non-myopes reported herein. However, there is an apparent discordance in the level of data and time usage differences observed between myopes and non-myopes. It is highly unlikely that the large data disparity is accurately reflected in the relatively small time difference found using the self-reported measure. Although statistically significant, the correlation between data usage and self-reported usage time in this study was weak, which possibly indicates low criterion validity for self-reported measures.[33] There is evidence to suggest that self-reported measures of smartphone use are typically underestimated and not reliable indicators of actual use.[34] Records of data usage, as collected herein, provide an objective, quantifiable and verifiable measure of phone use over an extended period of time, yielding a better indicator of smartphone behaviour than self-reported usage data. Furthermore, there is no validated questionnaire developed to assess subjective near work or smartphone usage, which is a limitation of any study that relies on self-reported data. Therefore the use of smartphone data as a surrogate indicator of phone use provides a better indicator of smartphone behaviour than self-reported usage data.[29] The extended period of data usage evaluated is particularly important in that it limits the possible influence of theoretical confounders such as time of week (weekday versus weekend). Additionally the data is likely more reflective of typical daily life and not limited to short-term recall which would influence self-reported time usage estimates.

Although gender-based differences in myopia prevalence in children have been identified in certain populations,[35] gender was not statistically significantly associated with myopia status in this study, which is in agreement with observations in the Northern Ireland Childhood Errors of Refraction (NICER) study in Northern Ireland. Perceptions relating to the possible ocular effects of smartphones were also explored as a means to elucidate the impact, if any, of such beliefs on the habitual usage of such devices. Our findings suggest that believing phone usage is deleterious to eye health does not limit use. This belief was expressed more often among myopes, in whom smartphone use was greatest.

A range of factors could be associated with the onset and/or progression of myopia in smartphone use which merit further investigation. These include excessive accommodation or closer working demands,[10,31,36] higher accommodative convergence/accommodation ratios,[37,38] and peripheral defocus.[5,39,40] Furthermore, bedtime mobile phone use can disturb and delay sleep,[41–43] and future research should continue to investigate associations between myopia and circadian rhythm, lack of sleep and poor sleep quality.[8,9,44]

Limitations of the study

The results of this study are limited in that the case control design limits any causal inferences regarding the observed association between smartphone use and myopia. Future studies should seek to address causality through prospective design. However, the study represents a large study sample of smartphone users across the entire education level and age spectrum during which myopia development and progression is most likely,[45] and thus, the period during which environmental influences may pose a significant risk to the development of myopic refractive error.

One consideration is how much of the data usage relates to visual tasks. This study predates the built-in 'screen time' app of iOS 12 that provides daily and weekly activity reports of the total time a person spends in each app they use.[46] Background programs as well as some apps (for example, apps which download files and videos or high-resolution video streaming apps such as YouTube and Netflix) use more data so smartphone data consumption does not necessarily correlate with time spent looking at a smartphone;[47] however, it is likely that any influence of such factors is balanced across the two study groups. It has also been demonstrated that the use of social networking apps account for the majority of active time spent on a smartphone and corresponding data traffic.[48] Interaction with these social media apps requires a high level of visual participation. Additionally, applications that play music and therefore do not require a person to look at a screen were not in the top applications that used most data in this study.

As the study was performed in a classroom rather than a clinical setting, a formal eye examination was not conducted as part of the study. However, a qualified optometrist carefully reviewed every participant who reported spectacle/contact lens use in order to determine their refractive status. This method is more robust than self-classification of myopia status which has been performed in a range of studies. Self-classification of myopia has been found to be reasonably reliable and provides lower-bound to any potential underestimation.[49] The possibility that some children may have had uncorrected refractive error may have led to an underestimation of the number of myopes. As a validation, the proportion of myopes in this study attending primary (< 13 years) and secondary school (13–18 years) was 15 and 26 per cent, respectively; comparable to the prevalence of myopia in schoolchildren reported in the recent Ireland Eye Study (12–13 years, 19.9 per cent) and to the UK NICER study (12–13 years, 16.4 per cent, 18–20 years, 18.6 per cent), so any underestimation is likely minimal.[3] The confirmation of the association between myopic parents and myopia in their children also affirms the validity of the myopic classification procedure.

Time spent outdoors was not recorded in the study and extensive screen time may influence time spent participating in outdoor activities, although mobile phone use is not limited to indoors or outdoors. Although we cannot be definitive as to whether more smartphone usage equates to less time outdoors, it is highly likely that the levels of daily usage reported herein would certainly compete with and limit the time available to children and adolescents for outdoors-based activities. Future studies should incorporate objective measures of light and outdoors exposure patterns to address this issue more comprehensively.[50]

Conclusion

The escalating prevalence of myopia is not a recent phenomenon and certainly predates smartphones, but the current generation of children are the first to grow up in an era of smartphone dependency. This study demonstrates an association between myopia and smartphone data usage. Children are now spending substantially more time focusing on proximal tasks compared to that observed in studies conducted in the pre-smartphone era, posing an additional environmental risk factor for myopia. Given the serious nature of the ocular health risks associated with myopia, our findings indicate that this relationship merits more detailed investigation.

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