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Smartphone Use Associated with Refractive Error in Teenagers

The Myopia App Study

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Purpose: To investigate the association between smartphone use and refractive error in teenagers using the Myopia app.

Design: Cross-sectional population-based study.

Participants: A total of 525 teenagers 12 to 16 years of age from 6 secondary schools and from the birth cohort study Generation R participated.

Methods: A smartphone application (Myopia app; Innovattic) was designed to measure smartphone use and face-to-screen distance objectively and to pose questions about outdoor exposure. Participants underwent cycloplegic refractive error and ocular biometry measurements. Mean daily smartphone use was calculated in hours per day and continuous use as the number of episodes of 20 minutes on screen without breaks. Linear mixed models were conducted with smartphone use, continuous use, and face-to-screen distance as determinants and spherical equivalent of refraction (SER) and axial length-to-corneal radius (AL:CR) ratio as outcome measures stratified by median outdoor exposure.

Main Outcome Measures: Spherical equivalent of refraction in diopters and AL:CR ratio.

Results: The teenagers on average were 13.7 ± 0.85 years of age, and myopia prevalence was 18.9%. During school days, total smartphone use on average was 3.71 ± 1.70 hours/day and was associated only borderline significantly with AL:CR ratio (β = 0.008; 95% confidence interval [CI], −0.001 to 0.017) and not with SER. Continuous use on average was 6.42 ± 4.36 episodes of 20-minute use without breaks per day and was associated significantly with SER and AL:CR ratio (β = −0.07 [95% CI, −0.13 to −0.01] and β = 0.004 [95% CI, 0.001−0.008], respectively). When stratifying for outdoor exposure, continuous use remained significant only for teenagers with low exposure (β = −0.10 [95% CI, −0.20 to −0.01] and β = 0.007 [95% CI, 0.001−0.013] for SER and AL:CR ratio, respectively). Smartphone use during weekends was not associated significantly with SER and AL:CR ratio, nor was face-to-screen distance.

Conclusions: Dutch teenagers spent almost 4 hours per day on their smartphones. Episodes of 20 minutes of continuous use were associated with more myopic refractive errors, particularly in those with low outdoor exposure. This study suggested that frequent breaks should become a recommendation for smartphone use in teenagers. Future large longitudinal studies will allow more detailed information on safe screen use in youth. *Ophthalmology 2021;■:1−8 © 2021 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).*

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Myopia is a refractive error caused by disproportionate eye growth during childhood and adolescence.[1] The prevalence of myopia is rising all over the world.[2,3] Currently, almost 50% of the young adults in Europe and 80% to 90% of the young adults in urban areas of East Asia are myopic.[2,4,5] Early onset of myopia results in higher degrees of myopia in adulthood.[6,7] This can lead to visual impairment and even blindness resulting from retinal complications later in life.[8,9] The rise in myopia prevalence in the last decade is caused by many lifestyle and behavioral changes.[10] For instance, spending less time outdoors is an established risk factor; the role of prolonged near work is still debated, but many reports conclude an association.[11−13] These environmental factors also may explain why children growing up in urban areas more often are myopic than those growing up in rural areas.[14−16]

In recent years, researchers have speculated that smartphone use is an additional risk factor for myopia. Time spent on smartphones adds considerably to the total hours spent on near work among teenagers.[17] However, the so-called myopia boom started in 1950,[18] when smartphones did not yet exist. Smartphones are relatively new, and children

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growing up with smartphones are yet to become adults. Long-term effects, including the influence on the myopia prevalence, are yet to be determined. Smartphone use is prone to underreporting and therefore is difficult to determine by questionnaire.[19] For the current study, we developed a smartphone application (the Myopia app; Innovattic) that registers smartphone use and face-to-screen distance electronically to allow for objective measurements. We assessed the associations among smartphone use, outdoor exposure, and refractive error as measured by the Myopia app and self-reported outdoor exposure. We hypothesized that increased smartphone use is associated with a more myopic refractive error and that this association may be modified by outdoor exposure.

Methods

Study Populations: Myopia App Study and Generation R

Teenagers 12 to 16 years of age from 2 cohorts were eligible to enrol in the study: participants in the Myopia App Study (MAS) and the Generation R study. The MAS participants were recruited from 6 secondary schools in semiurban areas in The Netherlands. Schools were asked to disseminate information on MAS among their pupils, and 300 teenagers from the first, second, and third grades (ages, 12−16 years) consented to participate (Fig S1, available at www.aaojournal.org). Generation R is a large, prospective, population-based birth cohort in which 9778 pregnant mothers were enrolled between 2002 and 2006. Details of the methodology of this study have been described elsewhere.[20,21] Of the initial cohort, 4929 children (50%) visited the research center at 13 years of age. The app measurements were introduced during the final part of the study phase in April 2019, and 225 teenagers signed informed consent (Fig S1).

The app and ophthalmic measurements were performed between November 2018 and December 2019 in both cohorts. Two participants did not undergo eye measurements; 361 participants installed the app. Valid smartphone and eye measurements were available for 272 participants, because 25% of participants did not allow the app to run in the background of the operating system or technical issues hampered registration (Fig S1). Written informed consent from both parents and the teenagers was obtained before eye examination and app measurements. The study protocol was approved by the Medical Ethical Committee of the Erasmus Medical Center, Rotterdam (identifiers, MEC-2018-005, NL63977.078.17 [MAS] and MEC-217.595/2002/20 [Generation R study]). The study project was conducted according to the tenets of the Declaration of Helsinki.

Mobile Application

The Myopia app was developed by the company Innovattic (www.innovattic.com) and was made available for the smartphone operation systems iOS and Android. This smartphone logging app registered smartphone use and face-to-screen distance (see next section). The teenagers received questions about outdoor exposure twice weekly through pop-up notifications in the app. To encourage the teenagers to answer all questions, gamification techniques were implemented in the app, that is, different levels were used to perform the measurements. Participants were rewarded with extra points after a questionnaire was completed, and an avatar received new gadgets (i.e., hat or sunglasses) with an increasing number of points. After 5 weeks, the teenagers were rewarded with an online shopping voucher with a value corresponding to the amount of questions answered (up to €7.50).

Smartphone Use

Smartphone use was measured over 5 weeks. The time of locking and unlocking the smartphone was registered using Unix time stamps, and participants were advised not to close the app. In that way, the app continued running in the background, which was needed because the closed operating systems of iOS and Android hampered continuous registration. We took particular care to identify measurement errors that occurred when participants (unintentionally) closed the app. Depending on whether the last measurement was registered as screen off or screen on before the app stopped running in the background, this resulted in days with very low smartphone use or extremely long continuous smartphone use. Days with fewer than 5 minutes of smartphone use in total or days with more than 5 hours of continuous use without locking the screen were excluded (on average, 7.9 days per participant [33.9%]), resulting in an average of 19.7 measurement days (standard deviation [SD], 14.5 measurement days; median, 17.0 measurement days; interquartile range [IQR] 7.0 to 30.0, 23 measurement days) per participant. To check for bias because of measurement error, we also excluded days with less than 1 minute of smartphone use in total or days with more than 4 hours of continuous use (on average, 8.7 days per participant [35.7%]), resulting in an average of 19.0 measurement days (SD, 14.0 measurement days; median, 17.0 measurement days; IQR 7.0 to 28.0, 21.0 measurement days) per participant, and days with less than 10 minutes of smartphone use in total. Excluding days with more than 6 hours of continuous use (on average, 7.4 days per participant [32.1%]) resulted in an average of 20.3 measurement days (SD, 14.7 measurement days; median, 18.0 measurement days; IQR 8.0 to 30.0, 22.0 measurement days) per participant. The main analyses were performed using the first data processing manner (excluding days with < 5 minutes in total and > 5 hours of continuous use). Sensitivity analyses were performed using the second (more strict) and third (less strict) data processing manner (excluding days with < 1 minute in total and > 4 hours of continuous use and excluding days with < 10 minutes in total and > 6 hours of continuous use) to ensure that the association between smartphone use and refractive error was not driven by our choice of excluding measurement days.

Smartphone use (hours per day) was calculated by summing the total time of smartphone use divided by the number of days the app was running. Continuous smartphone use was calculated by the sum of screen times of 20 minutes or longer divided by 20. For example, if a participant had 5, 53, 22, 19, and 68 minutes of smartphone use on one day, then continuous use was calculated by summing 53, 22, and 68 (143 minutes) divided by 20, that is, 7.15 episodes of 20 minutes of continuous smartphone use. Continuous use was determined by the sum of these episodes divided by the number of days the app was running. Smartphone use and continuous use were calculated for school days and non−school days separately. Non−school days consisted for 75.5% of weekend days and 24.5% of holidays. The density plots of smartphone use and continuous smartphone use during school days defined by the 3 different data processing manners are shown in Figure S2 (available at www.aaojournal.org).

Validation Study

We performed a validation study that included 5 Android users and 5 iOS users. They installed the Myopia app on their smartphone for 2 weeks. Smartphone use measured by the Myopia app was compared with smartphone use measured by the inbuilt screen time tracker of the smartphone. The Spearman correlation coefficient between the smartphone use measured by the Myopia app, and the smartphone use measured by the inbuilt app was calculated.

Face-to-Screen Distance

Face-to-screen distance was measured using the front camera of the smartphone. Android device users calibrated the app by holding their smartphone exactly 29.7 cm in front of their eyes (the length of the long side of an A4 piece of paper); iOS device users did not need to calibrate face-to-screen measurement because of the technical similarities among iPhones. Face-to-screen distance was measured when the app was active and open (i.e., when participants were filling out questions). The number of face-to-screen measurements on average was 592 measurements (SD, 1246 measurements; median, 272.0 measurements; IQR 152.0 to 555.3, 403.3 measurements) per person. Mean face-to-screen distance was calculated. Sensitivity analyses were performed excluding participants with fewer than 100 measurements to ensure that measurement reflected most commonly used smartphone distance.

Outdoor Exposure

Outdoor exposure was asked repeatedly in the app for 5 weeks. On Monday afternoon and Friday evening, the participants received the question: "How much time did you spend outdoors last Saturday/Sunday/Monday or Tuesday/Wednesday/Thursday/Friday? For example, cycling, sports, walking, playing outdoors, or being outdoors with friends or family." Mean outdoor exposure per day (in hours per day) was calculated for school days and non−school days separately.

Other Covariates

Sex, age at examination, season of app measurement, ethnic background, and operating system (iOS or Android) were considered as covariates. Ethnic background was defined according to the definitions by Health Statistics Netherlands, that is, based on the country of birth of the (grand) parents. It was assessed through a questionnaire in the app for the MAS participants and by questionnaires filled out by the parents for the Generation R participants and was stratified into European and non-European backgrounds. Operating system was assessed through the app.

Eye Measurements

The eye examination consisted of presenting monocular visual acuity with logarithm of the minimum angle of resolution−based Early Treatment Diabetic Retinopathy Study charts at 3 m by means of the fast Early Treatment Diabetic Retinopathy Study method. Ocular biometry was measured by Zeiss IOLMaster 500 or 700 (Carl Zeiss Meditec). Five axial length measurements per eye were averaged to calculate mean axial length; 3 measurements of corneal radius (K1 and K2) were averaged to calculate the mean corneal radius, and axial length-to-corneal radius (AL:CR) ratio was calculated. Cycloplegic refractive error of the nondominant eye was measured with handheld Retinomax 3 (Righton) in the MAS participants, of both eyes in the Generation R participants, both 30 minutes after 2 doses of cyclopentolate 1%. Spherical equivalent of refraction (SER) was calculated by the sum of the full spherical value plus half of the negative cylindrical value. Mean SER for Generation R participants was assessed by averaging SER of the right and left eyes. Myopia was defined as SER of −0.50 diopter (D) or less.

Data Analyses

Differences between participants who were included in the analyses and who were excluded because of missing data, as well as differences between the school-based cohort and Generation R cohort, were analyzed with independent *t* tests for continuous variables and chi-square tests for dichotomous variables. Spearman correlation coefficients were calculated for smartphone use, continuous use, face-to-screen distance, and outdoor exposure during school days and weekend days. To take into account the similarities between teenagers from the same study site, linear mixed models with restricted likelihood estimation from the nlmer package in R software (R Foundation for Statistical Computing) were used to perform the analyses (Table S1, available at www.aaojournal.org).[22] The associations between smartphone use, continuous use (20 minutes), outdoor exposure, and face-to-screen distance as exposures and SER and AL:CR ratio as outcomes variables were investigated, with random intercept for study sites (schools), and adjusted for age, sex, season of app measurement, and operating system (iOS or Android). The following sensitivity analyses were performed. First, outliers in smartphone use and continuous use were excluded, that is, > 4 / 6 hours continuous use, and days with < 1 / 10 minutes smartphone use (see above). Second, we additionally adjusted for outdoor exposure to ensure an independent association among smartphone use, continuous use, SER, and AL:CR ratio. Third, participants with fewer than 100 measurements for face-to-screen distance were excluded (see previous). Fourth, because of the large number of missing data for ethnicity and because the MAS participants were 97% European, we did not adjust for ethnicity in the main analyses but instead performed sensitivity analyses with European participants only. Finally, interaction analysis was performed with smartphone use, outdoor exposure, and an interaction term as exposures and SER and AL:CR ratio as outcomes variables, with random intercept for study sites (schools), and adjusted for age, sex, and operating system. Stratified analyses were performed for teenagers with high and low outdoor exposure based on the median. Analyses were performed in IBM SPSS version 25 and R statistical software version 3.6.1.

Results

The teenagers on average were 13.7 ± 0.85 years of age; 54% were girls. Myopia prevalence was 18.9%, SER was +0.40 ± 1.90 D, AL:CR ratio was 2.99 ± 0.11, and axial length was 23.4 ± 0.88 mm. The teenagers spent on average 3.71 ± 1.70 hours/day on their smartphone on school days and 3.82 ± 2.09 hours/day on non−school days, with an average face-to-screen distance of 29.1 ± 6.25 cm. Participants had 6.42 ± 4.36 episodes of 20 minutes of continuous use per day during school days and 7.10 ± 5.28 episodes during non−school days. Outdoor exposure was 2.37 ± 0.94 hours/day on school days and 2.77 ± 1.13 hours/day on non−school days. Participants with myopia demonstrated a more negative SER and larger AL:CR ratio and axial length compared with participants without myopia. Differences between participants with (n = 45) and without (n = 193) myopia regarding sex, ethnicity, smartphone use, continuous use, face-to-screen distance, outdoor exposure, season of app measurement, operating system, and study site did not reach statistical significance (Table 1).

Variables that differed between the MAS cohort and Generation R were age ($P = 0.02$), ethnic background ($P < 0.001$), and outdoor exposure during school days ($P = 0.01$). Participants who were included in the analyses were younger (13.7 years vs. 13.9 years; $P = 0.01$) and more often from a European ethnic background (86.5% vs. 67.9%; $P \leq 0.001$) than those who were

Table 1. General Characteristics

	Total (n = 272)	Missing (%)	Myopia (n = 45)	No Myopia (n = 193)	P Value
Age (yrs)	13.7 ± 0.85	0.0	13.5 ± 0.96	13.7 ± 0.87	0.36
Sex (female)	53.7	0.0	60.0	52.3	0.41
Ethnicity (European)	86.5	15.4	81.8	87.7	0.39
Spherical equivalent (diopters)	0.40 ± 1.90	12.5	−2.36 ± 2.10	1.04 ± 1.11	< 0.001
Myopia	18.9	12.5	NA	NA	NA
Axial length corneal radius ratio	2.99 ± 0.11	2.6	3.14 ± 0.13	2.96 ± 0.08	< 0.001
Axial length (mm)	23.4 ± 0.88	0.4	24.2 ± 0.91	23.2 ± 0.73	< 0.001
Smartphone use (hr/day)					
During school days	3.71 ± 1.70	7.7	3.75 ± 1.55	3.67 ± 1.73	0.78
During non−school days	3.82 ± 2.09	5.9	3.54 ± 2.11	3.77 ± 2.09	0.52
Continuous use (episodes of ≥ 20 min)					
During school days	6.42 ± 4.36	7.7	6.62 ± 4.32	6.13 ± 4.17	0.50
During non−school days	7.10 ± 5.28	5.9	6.51 ± 5.95	6.91 ± 5.11	0.66
Face-to-screen distance (cm)	29.1 ± 6.3	14.7	29.1 ± 7.47	29.4 ± 5.72	0.76
Outdoor exposure (hr/day)					
During school days	2.37 ± 0.94	11.8	2.10 ± 0.90	2.41 ± 0.96	0.06
During non−school days	2.77 ± 1.13	1.5	2.48 ± 1.21	2.83 ± 1.07	0.05
Season of app measurement		0.0			0.65
Spring	71.3		66.6	72.0	
Summer	20.2		20.0	19.2	
Autumn	8.5		13.3	8.8	
Operating system (Android)	60.7	0.0	68.9	59.1	0.24
Study site		0.0			0.16
Generation R	25.7		22.2	15.5	
School 1	36.4		28.9	44.6	
School 2	13.6		20.0	14.0	
School 3	8.8		11.1	8.3	
School 4	4.0		0.0	5.7	
School 5	4.0		8.8	3.6	
School 6	7.4		8.8	8.3	

Data are presented as mean ± standard deviation or percentage.

not included because of missing data on smartphone use and eye measurements. Differences between children included in the analysis and those excluded regarding sex, SER, myopia, axial length, and AL:CR ratio were not observed. The Spearman correlation coefficient between the Myopia app and the inbuilt app in our validation study was 0.97 (Fig S3, available at www.aaojournal.org).

Correlations between smartphone use, face-to-screen distance, and outdoor exposure are depicted in Figure 1. Smartphone use, face-to-screen distance, and outdoor exposure were distributed normally; continuous use was slightly right skewed (Fig S2). Smartphone use was correlated strongly with continuous use (r = 0.86 and $P < 0.001$ during school days; $r = 0.90$ and $P < 0.001$ during weekend days), and outdoor exposure was correlated inversely with smartphone use and continuous use (smartphone use: $r = -0.19$ and $P = 0.006$ during school days; $r = -0.21$ and $P = 0.003$ during weekend days; continuous use: $r = -0.24$ and $P < 0.001$ during school days; $r = -0.26$ and $P < 0.001$ during weekend days). Face-to-screen distance was not correlated with smartphone use, continuous use, or outdoor exposure.

Continuous use during school days was associated with SER (per each extra episode of 20 minutes continuous use: $\beta = -0.07$ [95% CI, −0.13 to −0.01]) and AL:CR ratio ($\beta = 0.004$ [95% CI, 0.001−0.008]; Fig 2). Smartphone use during school days showed a similar trend and was borderline associated significantly with AL:CR ratio ($\beta = 0.008$ [95% CI, −0.001 to 0.017]) but not with SER ($\beta = -0.09$ [95% CI, −0.25 to 0.07]). Outdoor exposure was associated with SER ($\beta = 0.33$ [95% CI, 0.07−0.60] and $\beta = 0.32$ [95% CI, 0.10−0.55] both during school days) and with AL:CR ratio during non−school days ($\beta = -0.016$ [95% CI, −0.029 to −0.003]). Face-to-screen distance, continuous use during non−school days, and smartphone use during non−school days were not associated with SER or AL:CR ratio (Table 2). Sensitivity analyses with different definitions of smartphone use or adjustment for outdoor exposure yielded similar results; excluding non-Europeans and those with missing data on ethnicity resulted in similar, albeit not significant,

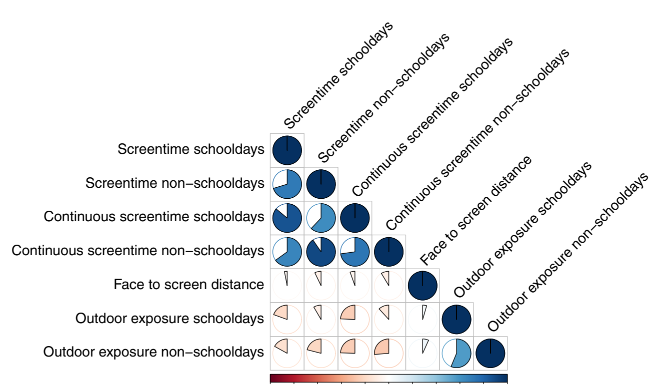

Figure 1. Diagram showing correlations between smartphone use, continuous use, face-to-screen distance, and outdoor exposure during school days and holidays. Dark blue represents a positive correlation of 1, whereas dark red represents a negative correlation of −1.

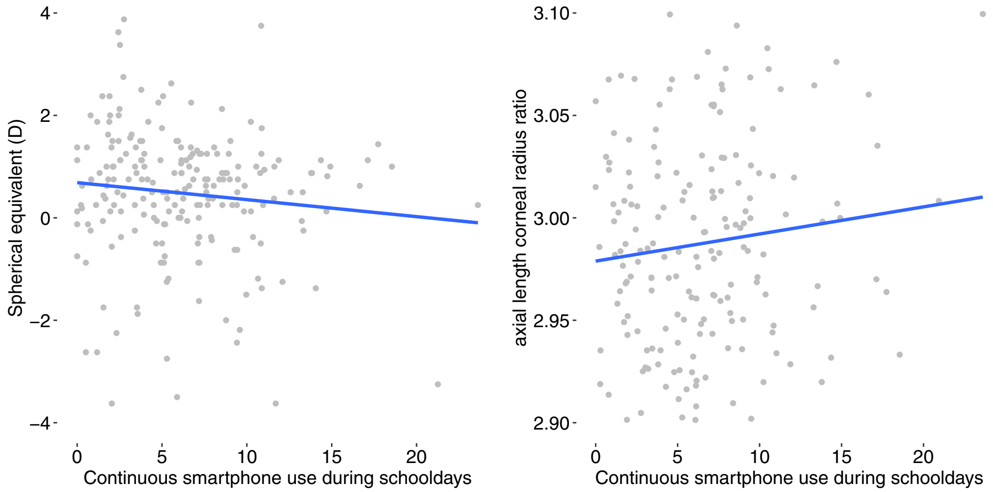

Figure 2. Scatterplots showing the association between continuous smartphone use (episodes of ≥ 20 minutes) and (**A**) spherical equivalent and (**B**) axial length-to-corneal radius ratio. Blue lines represent the unadjusted regression lines. D = diopter.

β coefficients. Face-to-screen distance excluding participants with fewer than 100 measurements was not associated significantly with SER or AL:CR ratio (Table S1 available at www.aaojournal.org).

Stratified analyses showed that the association between continuous use and SER and AL:CR ratio was observed for teenagers with low outdoor exposure (β = −0.10 [95% CI, −0.20 to −0.01] for SER and β = 0.007 [95% CI, 0.001−0.013] for AL:CR ratio) but not for teenagers with high outdoor exposure (Table 3). However, the interaction term between continuous use and outdoor exposure was not significant (*P* = 1.00 for SER; *P* = 0.40 for AL:CR ratio).

Discussion

In this study, we used a mobile application to determine smartphone use in relationship to refractive error. We showed that those with more episodes of continuous use demonstrated a more myopic refractive error. This association disappeared in teenagers with high outdoor exposure, suggesting that outdoor exposure may moderate this effect.

Smartphone use is a relatively new behavior among youth. It became increasingly popular after the introduction of the first iPhone in 2008. Worldwide, 139 million smartphones were sold in 2008, which increased to 1496 million smartphones sold in 2016. Most smartphone owners are from the United States and Western Europe, but the Chinese market is also on the rise.[23] Research reports addressing the effect of smartphone use on myopia in teenagers are scarce. In our study, smartphone use was 3.71 hours/day during school days according to the Myopia app, which is comparable with the 4 hours/day among 19-year-old

Table 2. Linear Regression Analyses of Smartphone Use, Continuous Use during School Days and Non−School Days, and Face-to-Screen Distance on Spherical Equivalent and Axial Length-to-Corneal Radius Ratio

	Spherical Equivalent Refraction					Axial Length-to-Corneal Radius Ratio				
	No.	*Estimate*	*Standard Error*	*95% Confidence Interval*	*P Value*	*No.*	*Estimate*	*Standard Error*	*95% Confidence Interval*	*P Value*
Smartphone use (hr/day) during school days	207	−0.09	0.08	−0.25 to −0.07	0.30	227	0.008	0.005	−0.001 to −0.017	0.10
Continuous use (≥ 20 min) during school days	207	−0.07	0.03	−0.13 to −0.01	0.03	227	0.004	0.002	0.001−0.008	0.02
Smartphone use (hr/day) during non−school days	204	−0.02	0.10	−0.21 to −0.18	0.88	226	0.002	0.006	−0.010 to −0.013	0.75
Continuous use (≥ 20 min) during non−school days	204	−0.03	0.03	−0.11 to −0.04	0.34	226	0.002	0.002	−0.002 to −0.006	0.29
Outdoor exposure (hr/day) during school days	213	0.33	0.13	0.07−0.60	0.01	235	−0.011	0.008	−0.027 to −0.005	0.17
Outdoor exposure (hr/day) during non−school days	235	0.32	0.11	0.10−0.55	0.004	261	−0.016	0.006	−0.029 to −0.003	0.02
Face-to-screen distance	201	0.00	0.02	−0.04 to −0.04	0.98	226	0.000	0.001	−0.003 to −0.002	0.84

Adjusted for age, sex, season of app measurement, and operating system.

Table 3. Linear Regression Analyses of Smartphone Use and Continuous Use during School Days and Holidays on Spherical Equivalent Refraction and Axial Length-to-Corneal Radius Ratio Stratified by High versus Low Outdoor Exposure

Outdoor Exposure	Smartphone Use during School Days	Spherical Equivalent Refraction					Axial Length-to-Corneal Radius Ratio				
		No.	Estimate	Standard Error	95% Confidence Interval	P Value	No.	Estimate	Standard Error	95% Confidence Interval	P Value
Low	Hours/day	99	−0.12	0.13	−0.36 to −0.12	0.35	112	0.010	0.007	−0.004 to −0.024	0.17
	Continuous use (≥20 min)	99	−0.10	0.05	−0.20 to −0.01	0.03	112	0.007	0.003	0.001−0.013	0.02
High	Hours/day	99	−0.04	0.11	−0.25 to −0.17	0.72	105	0.003	0.006	−0.009 to −0.014	0.65
	Continuous use (≥20 min)	99	−0.02	0.05	−0.12 to −0.07	0.61	105	0.001	0.002	−0.003 to −0.006	0.59

Adjusted for age, sex, season of app measurement, and operating system.

university students from the United States measured with the Moment app.[17] A Chinese study showed that 1 hour/day increase in smartphone use was associated with −0.28 D SER after adjustment for age, sex, reading behavior, outdoor exposure, and sleep in 566 children 6 to 14 years of age.[24] We observed a particular association with continuous use: SER was −0.07 D more myopic and AL:CR ratio was 0.005 larger for each extra episode of 20 minutes of continuous use. The SER was −0.10 D more myopic and the AL:CR ratio 0.008 larger for each hour of daily smartphone use, but this association was not significant ($P = 0.22$ for SER and $P = 0.07$ for AL:CR ratio). Studies focussing on reading behavior also reported that continuous reading was associated more prominently with myopia than total reading time,[12,25] despite their high correlation. Continuous near work may be a more important risk factor than time spent on near work, suggesting that regular breaks during near work (including smartphone use) will help to prevent myopia from developing in teenagers.

Although the association between screen time and myopia was debatable for a long time,[26,27] recently, the results of many studies support the presence of such an association.[28−32] Exposure to screen time before the age of 1 year was associated with myopia (prevalence ratio, 4.02) among 26,433 preschool children in China.[28] Irish school children who spent more than 3 hours/day on a screen more often were myopic (odds ratio, 3.70), and a 1-hour increase in computer use was associated with myopia (odds ratio, 1.005) in a former study among 9-year-old children.[29,30] Adolescents using a screen for more than 6 hours/day more often were myopic than those with fewer than 2 hours/day of screen use (odds ratio, 1.95) in Copenhagen.[31] A longitudinal study among 5- to 15-year-old children from India showed that more than 7 hours/day of screen time also was associated with myopia progression compared with fewer than 4 hours/day of screen time (odds ratio, 3.53).[32] Together with our current findings, this suggests that screen use may become an established risk factor for myopia.

Reading distance has been identified as a risk factor for myopia in many cross-sectional and longitudinal studies.[12,25,30,33] Reading distance often was measured using a questionnaire for parents, and these studies reported positive associations for 30 cm,[25,30] 20 cm,[12] and 33 cm.[33] The sensitivity analysis in our study showed that a 1-cm-shorter face-to-screen distance was associated with −0.03 D (95% CI, 0.02 to −0.08 D) more myopia, but this association failed to reach statistical significance. Face-to-screen distance was not correlated with smartphone use in our study. Ip et al[25] and Li et al[12] did not identify a correlation between reading distance and reading time either, adding to the discrepancies in the associations with refractive error for continuous smartphone use and face-to-screen distance.

Strengths of this study are the objective measurement of smartphone use and face-to-screen distance using the Myopia app. The Myopia app was made available for both iOS and Android devices and thus was accessible to almost any smartphone user. Our validation study showed a high correlation between smartphone use measured by the Myopia app and smartphone use measured by the inbuilt screen time tracker of the smartphone, supporting an accurate registration. Sensitivity analyses with different definitions of smartphone use yielded similar results, indicating that the association was robust. Nevertheless, some limitations should be borne in mind. First, the cross-sectional design of this study hindered causal interpretation of the data. Current smartphone use most likely reflects previous smartphone use; however, cumulative smartphone use depends on the age of smartphone acquisition. In the Netherlands, most children own a smartphone from the age of 10 years onward,[34] and we expect that most teenagers in our study already had 2 to 3 years of smartphone exposure time. Second, the relatively large number of days with unrealistic measurements and the limited sample size may have led to inconclusive results. Future studies should incorporate a longitudinal study design in a large sample. Third, some activities on the smartphone, like calling someone, were registered as smartphone use, while not involving near work. Yet because time spent on calling is usually very short in teenagers of this age, we do not expect that this had a major influence on our results.[34] Finally, only the nondominant eye was measured with cycloplegia in the MAS participants. Nondominant eyes may be more hyperopic than dominant eyes in children with anisometropia.[35,36] This may have resulted in an underrepresentation of myopia in the MAS participants but did not distort AL:CR ratio because this was measured in both eyes.

In conclusion, our study showed that Dutch teenagers use their smartphone almost 4 hours/day. A higher number of episodes of more than 20 minutes of continuous use was associated with more myopic SER and a larger AL:CR ratio. This association was not present in teenagers with high outdoor exposure, suggesting that outdoor exposure moderates the association. Because smartphone use is becoming increasingly popular, awareness of the potential negative consequences of prolonged smartphone use is warranted. The 20-20-2 rule as recommended earlier remains good advice.[37]

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Footnotes and Disclosures

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Abbreviations and Acronyms:
AL:CR = axial length-to-corneal radius; **CI** = confidence interval; **D** = diopter; **iOS** = iPhone operating system; **IQR** = interquartile range; **MAS** = Myopia App Study; **SD** = standard deviation; **SER** = spherical equivalent of refraction.

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