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ORIGINAL ARTICLE

Association between Exposure to Smartphones and Ocular Health in Adolescents

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ABSTRACT

Purpose: Smartphone use has dramatically increased in recent years. Smartphones may have adverse health effects, particularly on the eyes, because users stare at the screen for a much longer time than they do with ordinary mobile phones. The objective of this study was to elucidate the relationship between smartphone use and ocular symptoms among adolescents.

Methods: Information on smartphone use and ocular symptoms (blurring, redness, visual disturbance, secretion, inflammation, lacrimation and dryness) related to eye fatigue and strain from 715 adolescent subjects from three cities in Korea was obtained using a structured questionnaire. Ocular health was scored using number of ocular symptoms. Odds ratios (ORs), 95% confidence intervals (95% CIs) and *p*-values for ocular symptoms were calculated with binomial and multinomial logistic regression models.

Results: Higher prevalence rates for ocular symptoms were observed in groups with greater exposure to smartphones ($p < 0.05$). Longer daily smartphone use was associated with a higher likelihood of having multiple ocular symptoms (5–7 symptoms out of 7 symptoms; $p = 0.005$). Excessive/intermittent use (>2 hours daily and ≤2 hours continuously) and excessive/persistent use (>2 hours daily and >2 hours continuously) compared to shorter use (<2 hours daily) were associated with multiple ocular symptoms (OR 2.18, 95% CI 1.09–4.39; OR 2.26, 95% CI 1.11–4.57, respectively). A higher lifetime exposure to smartphones was associated with a higher likelihood of having multiple ocular symptoms (OR 3.05, 95% CI 1.51–6.19; $p = 0.001$).

Conclusion: Increasing exposure to smartphones can have a negative impact on ocular health in adolescents.

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Adolescent; computer vision syndrome; lifetime exposure; ocular symptoms; smartphone

Introduction

Since its introduction in the late 2000s, smartphone use has been growing rapidly. In Korea, 60% of the population was reported as using smartphones in August 2012, only a few years after its introduction.[1] The rise in the use of mobile phones, including smartphones, has raised concerns because many studies have reported associations between the use of mobile phones and health outcomes such as malignant melanoma of the eyes, headaches, brain tumors and leukemia.[2–6]

Smartphones differ from ordinary mobile phones in the manner of use. While the main purpose of mobile phones has been for calling and talking on the phone, smartphones involve more interactions in which the eye is involved, such as sending text messages, watching video clips and playing games. Therefore, the time users spend consistently staring at the screen is longer with smartphones than with ordinary mobile phones. It has been speculated that the increase in smartphone use could have adverse effects on ocular health.

Adolescents tend to use these multimedia functions more often, and the time they spend using a smartphone is higher than that of adults.[7] In fact, their usage rate was highest among all age groups as of December 2013.[7] Although smartphone use among adolescents is growing rapidly, there have not been many studies on the effects of smartphone use on the ocular health of adolescents.

There are some studies investigating the relationship between mobile phone use and ocular health, however, many were not able to show a close relationship.[4,5] In addition, there are some, but few, studies assessing the relationship between smartphone use and ocular health.[8] Unlike previous studies that used the number

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of years a user has owned a mobile phone as the risk factor for ocular symptoms,[4] we hypothesized the number of hours a person used a smartphone per day, the number of hours a person used a smartphone continuously per day and the lifetime exposure to smartphones were the main risk factors. The aim of this study was to investigate the associations between smartphone use and ocular symptoms through a cross-sectional study on Korean adolescents in December 2013.

Materials and methods

Study population

Study participants were students from three cities in Korea (Seoul, Busan and Siheung) in December 2013. A total of 734 subjects participated in this study. We excluded 18 subjects who were missing information on the possession of a smartphone and one subject who was missing information on sex. A total of 715 subjects (442 male, 273 female) were included in the analysis. We received written informed consent from all participants, and the Institutional Review Board on Human Research at Seoul National University approved the design of this study (reference C-1401-014-545).

Data collection

A structured questionnaire was used to obtain information on general characteristics and lifestyle factors. The criteria for self-reported ocular symptoms used in the questionnaire were based on studies by Balik and colleagues[5] and Kucer.[4] The questionnaire was self-administrated with written instructions but without assistance from the research team on-site. Participants were asked whether they experienced any of the following seven symptoms in their ocular health; vision blurring, redness, visual disturbance, secretion, inflammation, lacrimation and dryness. They were also asked about whether they owned a smartphone, the number of years they had owned a smartphone, the average number of hours they used a smartphone per day (≤1, 2, 3, 4 or ≥ 5 hours), and the number of hours they used a smartphone continuously without stopping per day. Information on factors that may have an effect on ocular symptoms other than smartphone use such as the use of glasses or contact lenses, the number of hours the participants watched television or used a computer or other miscellaneous electronic devices per day were also collected.

Exposure and outcome variables

Seven self-reported ocular symptoms over the past year were used to generate an ocular symptom score (OSS) and each symptom was scored on a scale of 0 (no symptoms) to 1 (having symptoms of subjectively uncomfortable degrees). OSS was calculated by summing scores of each symptom. We classified three risk groups by OSS; 0–2, 3–4 and 5–7 symptoms.

The other outcome variable was ocular symptom cluster score (OSCS). By using factor analysis on the seven symptoms,[9] three clusters were classified; (1) blurring and redness, (2) visual disturbance, secretion and dryness, and (3) inflammation and lacrimation. Each cluster was scored on a scale of 0 (not reporting the symptoms within the cluster) to 1 (reporting the symptoms within the cluster) and the OSCS was calculated by summing scores of each cluster. We classified four risk groups by OSCS; 0, 1, 2 and 3 clusters.

Exposure variables were defined in two ways; "daily smartphone exposures" and "cumulative lifetime exposures." The first variable, "daily smartphone exposures," is the number of hours participants used a smartphone daily (hours/day). We divided daily exposure levels to smartphones into three levels initially; "shorter use" (subjects who used a smartphone for <2 hours/day), "intermediate use" (subjects who used a smartphone for 2 hours/day), and "excessive use" (subjects who used a smartphone for >2 hours/day), with the cut-off value of 2 hours/day, which was the median value of the number of hours subjects spent using their smartphones per day. Additionally, the "excessive use" group was divided again into two exposure levels by the continuity of smartphone use; "excessive/intermittent use" (subjects who used a smartphone for >2 hours/day but used a smartphone continuously for ≤2 hours/day per occasion), and "excessive/persistent use" (subjects who used a smartphone for >2 hours/day and used a smartphone continuously for >2 hours/day per occasion), with the cut-off value of 2 hours/day, which was the median value of the number of hours subjects spent using smartphones continuously per occasion. We calculated the second exposure variable, "cumulative lifetime exposures," by using the equation daily use duration (hours/day) × years of use in lifetime hours. Cumulative lifetime exposures were divided into four exposure levels as quartiles; "lower exposure" (exposure to smartphones for ≤3 lifetime hours), "intermediate exposure" (exposure to smartphones for 4–8 lifetime hours), "high exposure" (exposure to smartphones for 9–12 lifetime hours), and "extreme exposure" (exposure to smartphones for >12 lifetime hours).

Statistical analysis

General characteristics of the study population were compared with the Mantel-Haenszel trend test

(statistical significance was set at $p < 0.05$). The increasing trend in prevalence rates according to exposure levels was compared with the Mantel-Haenszel trend test. Odds ratios (ORs), corresponding 95% confidence intervals (CIs) and p-values of risk factors were calculated using binomial and multinomial logistic regression models. All models were adjusted for age, sex, daily sleep duration, use of contact lenses, computer use and city, except the models with participants excluding contact lens users, which were adjusted for age, sex, daily sleep duration, computer use and city. The adjustments were made because the six criteria were significantly different in groups divided according to the number of symptoms. All statistical analyses were done using SAS statistical software version 9.3 (SAS Inc, Cary, NC, USA).

Results

Table 1 shows the general characteristics of the study population. A total of 715 subjects (61.8% male, 38.2% female) were included in the analysis, and the mean age was 15.0 years. Sex ($p < 0.001$), age ($p < 0.001$), sleep duration ($p < 0.001$), contact lens use ($p < 0.001$), computer use ($p = 0.004$) and city ($p < 0.001$) had significant relationships to reporting more ocular symptoms. Female subjects were more likely to report ocular symptoms than male subjects although there were no significant differences between the two sexes in their smartphone use, such as daily use hours and daily continuous use hours (data not shown).

Table 2 shows increasing prevalence rates and ORs of the respective ocular symptoms according to duration of daily smartphone use (hours/day) and lifetime exposure to smartphones (lifetime hours). Increasing ORs of ocular symptoms by longer and continuous duration of daily smartphone use were seen in two ocular symptoms; inflammation (excessive/persistent use OR 1.88, 95% CI 1.12–3.16) and lacrimation (excessive/intermittent use OR 1.96, 95% CI 1.22–3.14; excessive/persistent use OR 2.12, 95% CI 1.31–3.46) Increasing ORs were also seen according to increasing lifetime exposure to smartphones; redness (OR 2.05, 95% CI 1.24–3.38) and lacrimation (intermediate exposure OR 1.92, 95% CI 1.21–3.05; higher exposure OR 1.95, 95% CI 1.22–3.12; extreme exposure OR 2.49, 95% CI 1.54–4.03).

Results using the OSCS based on the factor analysis of the seven symptoms also showed a similar tendency in association with daily and cumulative lifetime exposure levels of smartphones (Supplemental Table 1 – online only).

Table 3 shows the multinomial analysis by number of ocular symptoms (OSS). Although excessive/intermittent and excessive/persistent use groups had increased likelihoods of being in the 5–7 OSS group compared to the shorter use group (OR 2.18, 95% CI 1.09–4.39 and OR 2.26, 95% CI 1.11–4.57, respectively), the two ORs were not significantly different in the 95% CIs in both exposure groups. After excluding contact lens users, the excessive/intermittent use group had a 2.21-fold higher likelihood of being in the 5–7 OSS group (95% CI 1.06–4.60), and the excessive/persistent use group had a 2.47-fold higher likelihood of being in the 5–7 OSS group (95% CI 1.16–5.25).

The population with a lifetime exposure >12 lifetime hours (extreme exposure group), compared to the population with a lifetime exposure ≤3 lifetime hours(lower exposure group), had a 3.05–fold higher likelihood of being in the 5–7 OSS group (95% CI 1.51–6.19). After excluding contact lens users, the extreme exposure group had a 2.95-fold higher likelihood of being in the 5–7 OSS group (95% CI 1.39–6.27).

Discussion

This study shows that longer smartphone use per day can increase the prevalence rates and ORs of each ocular symptom and the likelihood of having multiple ocular symptoms. Lifetime exposure to smartphones, calculated by multiplying the daily hours of smartphone use with the years of smartphone use, was also associated with a higher prevalence for each symptom and the likelihood of having multiple ocular symptoms.

Two prior studies on the use of mobile phones reported that mobile phones have some, but few, adverse effects on the eyes.[4,5] Kucer divided subjects by duration of mobile phone use (>2 years vs. <2 years) and surveyed complaints of six ocular symptoms such as blurring of vision, redness of the eyes, vision disturbance, secretion of the eyes, inflammation in the eyes and lacrimation of the eyes, and compared prevalence rates of ocular symptoms in subjects who possessed mobile phones for >2 years to those in subjects who possessed mobile phones for <2 years.[4] Our study gathered more detailed information on exposure to smartphones (daily smartphone use in hours per day, continuous hours of smartphone use and total number of years of smartphone use) and included seven ocular symptoms which were the six symptoms used by Balik and co-workers[5] and Kucer[4] and one additional symptom, dryness of the eyes. We also included questions on lifestyle factors in our questionnaire. Therefore, our detailed questionnaire could decrease the likelihood of misclassification of exposure factors. Our study population was larger compared to Kucer's study population,[4] which consisted of university students; we confined our

Table 1. General characteristics of 715 adolescents in Korea[a], 2013.

	Ocular symptom score based on number of symptoms			
	0–2	3–4	5–7	
	n (%)	*n* (%)	*n* (%)	*p*-value[b]
Sex				
Male	199 (76.5)	170 (60.3)	62 (39.7)	<0.001
Female	61 (23.5)	112 (39.7)	94 (60.3)	
Age, years				
≤ 14	133 (51.2)	106 (37.6)	58 (37.2)	<0.001
15	70 (26.9)	74 (26.2)	29 (18.6)	
≥16	57 (21.9)	102 (36.2)	69 (44.2)	
Sleep duration, hours/day				
≤ 6	73 (28.2)	127 (45.0)	76 (48.7)	<0.001
7	119 (46.0)	109 (38.7)	59 (37.8)	
≥ 8	67 (25.9)	46 (16.3)	21 (13.5)	
Wearing glasses				
Yes	145 (56.0)	125 (44.5)	84 (54.2)	0.422
No	114 (44.0)	156 (55.5)	71 (45.8)	
Wearing contact lenses				
Yes	13 (5.0)	36 (12.8)	42 (26.9)	<0.001
No	246 (95.0)	246 (87.2)	114 (73.1)	
Computer use, hours/day				
≤ 1	141 (54.4)	180 (64.1)	105 (67.7)	0.004
> 1	118 (45.6)	101 (35.9)	50 (32.3)	
Television watching, hours/day				
≤ 1	138 (53.5)	159 (56.6)	93 (59.6)	0.217
> 1	120 (46.5)	122 (43.4)	63 (40.4)	
Electronic devices use[c], hours/day				
≤ 1	195 (76.5)	198 (71.0)	119 (76.8)	0.846
> 1	60 (23.5)	81 (29.0)	36 (23.2)	
City				
Seoul	10 (3.9)	38 (13.5)	49 (31.4)	<0.001
Busan	205 (78.9)	173 (61.4)	79 (50.6)	
Siheung	45 (17.3)	71 (25.2)	28 (18.0)	

[a]Participants were adolescents aged 14–18 years who were from three cities (Seoul, Busan and Siheung).
[b]Mantel-Haenszel chi-square test for trend.
[c]Number of hours/day participants used miscellaneous electronic devices other than a smartphone, computer or television, such as a mobile phone that is not a smartphone, portable media player, tablet personal computer, gaming devices, etc.

study population to adolescents who may be more susceptible to the effects of smartphones.[10] Furthermore, because only one symptom was shown to increase in subjects who used mobile phones for a greater number of years in the study of Kucer,[4] we studied the effects of smartphones for which the effects we believed were greater than those of mobile phones. Unlike other electronic devices including mobile phones, smartphones are used within a proximal distance from the eyes. It has been suggested that smartphones affect distance visual acuity when used at a close distance from the eyes.[11] The time spent using a smartphone is generally longer than that of a mobile phone and smartphones are used longer continuously than mobile phones, which led to significant results on ocular symptoms in this study.

It has been suggested that higher lifetime exposure to smartphones could be associated with various diseases. Although there are no studies that have investigated the effects of lifetime exposure to smartphones on ocular health, there has been one study which showed the effects of lifetime exposure to mobile phones on brain tumors.[12] Furthermore, in that study, mobile phone users whose age at first exposure to mobile phones was <20 years were at higher risk of diseases such as acoustic neuroma than users whose age at first exposure was 20–49 years and 50–80 years.[12] We showed that lifetime exposure to smartphones increases the risk of ocular symptoms. Because today's adolescents will have a higher lifetime exposure to smartphones than that of today's adults,[10] more caution should be taken by adolescents with their smartphone use.

Contact lens users are more likely to develop early dry eye syndrome by ocular surface alterations,[13] and the increasing use of digital devices by contact lens users is more likely to result in dry eye symptoms.[14] In this study, the prevalences of multiple ocular symptoms in groups with higher exposure were higher among total participants than among participants excluding contact lens users.

Biologically, the effects of smartphones on ocular symptoms can be explained by two types of

Table 2. Smartphone exposures and likelihood of having ocular symptoms in a binomial logistic regression model in adolescents, Korea.

	Blurring	Redness	Visual disturbance	Secretion	Dryness	Inflammation	Lacrimation
Daily smartphone exposure[c]							
Shorter use							
Prevalence, %	16.0	13.2	17.5	18.8	13.6	13.4	13.9
OR (95% CI)[a]	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Intermediate use							
Prevalence, %	26.3	23.7	27.0	27.1	26.8	29.2	26.9
OR (95% CI)[a]	1.02 (0.63–1.65)	1.19 (0.73–1.95)	1.05 (0.57–1.92)	0.76 (0.42–1.36)	1.36 (0.85–2.16)	1.68 (1.02–2.75)	1.56 (0.99–2.45)
Excessive/intermittent use							
Prevalence, %	28.2	34.8	27.8	28.1	31.6	29.2	30.2
OR (95% CI)[a]	1.00 (0.61–1.65)	2.08 (1.26–3.43)	1.03 (0.55–1.91)	1.33 (0.68–2.57)	1.63 (1.01–2.65)	1.63 (0.98–2.72)	1.96 (1.22–3.14)
Excessive/persistent use							
Prevalence, %	29.4	28.2	27.8	26.0	28.0	28.3	29.1
OR (95% CI)[a]	1.26 (0.76–2.08)	1.57 (0.94–2.63)	1.13 (0.60–2.12)	1.43 (0.71–2.85)	1.51 (0.92–2.49)	1.88 (1.12–3.16)	2.12 (1.31–3.46)
p-trend[b]	0.011	<0.001	0.351	0.032	<0.001	0.007	<0.001
Lifetime smartphone exposure[d]							
Lower exposure							
Prevalence, %	16.1	13.8	16.4	18.8	15.5	16.1	13.2
OR (95% CI)[a]	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Intermediate exposure							
Prevalence, %	24.3	23.5	22.7	25.6	23.3	22.5	26.2
OR (95% CI)[a]	1.06 (0.65–1.73)	1.31 (0.80–2.14)	1.02 (0.54–1.91)	0.87 (0.48–1.57)	1.04 (0.65–1.66)	1.01 (0.61–1.65)	1.92 (1.21–3.05)
Higher exposure							
Prevalence, %	25.5	24.8	24.2	26.3	27.7	28.1	26.5
OR (95% CI)[a]	1.04 (0.64–1.71)	1.28 (0.78–2.12)	1.18 (0.62–2.22)	1.19 (0.62–2.27)	1.30 (0.81–2.08)	1.48 (0.90–2.41)	1.95 (1.22–3.12)
Extreme exposure							
Prevalence, %	34.1	37.9	36.7	29.3	33.5	33.3	34.1
OR (95% CI)[a]	1.29 (0.78–2.11)	2.05 (1.24–3.38)	1.54 (0.83–2.85)	1.32 (0.68–2.58)	1.31 (0.80–2.12)	1.55 (0.94–2.54)	2.49 (1.54–4.03)
p-trend[b]	0.005	<0.001	0.037	0.066	<0.001	0.005	<0.001

[a]ORs and 95% CIs calculated from binomial logistic regression models adjusted for sex, age, sleep duration, use of contact lenses, computer use and city.
[b]Trend tests were conducted in full logistic regression models adjusted for sex, age, sleep duration, use of contact lenses, computer use and city.
[c]Daily smartphone exposures were classified into four exposure groups; shorter use (<2 hours/day), intermediate use (2 hours/day), excessive/intermittent use (>2 hours/day but continuous use ≤2 hours/occasion), and excessive/persistent use (>2 hours/day and continuous use >2 hours/occasion).
[d]Lifetime smartphone exposures were calculated by the equation daily use duration in hours/day × years of use, and was classified into four exposure groups; lower exposure (≤3 lifetime hours), intermediate exposure (4–8 lifetime hours), high exposure (9–12 lifetime hours), and extreme exposure (>12 lifetime hours).
OR, odds ratio; CI, confidence interval.

Table 3. Relationship between smartphone exposure and likelihood of having more ocular symptoms based on number of symptoms in multinomial logistic regression model in adolescents, Korea.

	Ocular symptom score (OSS), *n* (%)			Multinomial logistic regression model, OR (95% CI)[a]	
	0–2	3–4	5–7	OSS 3–4 vs. 0–2	OSS 5–7 vs. 0–2
Total participants[b]					
Daily smartphone exposure					
Shorter use	68 (26.5)	45 (16.3)	19 (12.3)	1.00 (reference)	1.00 (reference)
Intermediate use	89 (34.6)	72 (26.1)	34 (22.1)	1.07 (0.65–1.78)	1.20 (0.60–2.38)
Excessive/intermittent use	51 (19.8)	86 (31.2)	50 (32.5)	1.88 (1.09–3.22)	2.18 (1.09–4.39)
Excessive/persistent use	49 (19.1)	73 (26.5)	51 (33.1)	1.68 (0.96–2.93)	2.26 (1.11–4.57)
Lifetime smartphone exposure					
Lower exposure	64 (25.0)	50 (17.9)	19 (12.2)	1.00 (reference)	1.00 (reference)
Intermediate exposure	82 (32.0)	68 (24.4)	31 (19.9)	0.99 (0.59–1.64)	1.26 (0.62–2.54)
Higher exposure	65 (25.4)	76 (27.2)	40 (25.6)	1.20 (0.71–2.02)	1.65 (0.82–3.32)
Extreme exposure	45 (17.6)	85 (30.5)	66 (42.3)	1.76 (1.01–3.07)	3.05 (1.51–6.19)
Participants excluding contact lens users[b]					
Daily smartphone exposure					
Shorter use	68 (27.8)	43 (17.8)	17 (14.9)	1.00 (reference)	1.00 (reference)
Intermediate use	84 (34.3)	69 (28.6)	29 (25.4)	1.15 (0.69–1.92)	1.21 (0.59–2.48)
Excessive/intermittent use	50 (20.4)	70 (29.1)	36 (31.6)	1.71 (0.98–2.98)	2.21 (1.06–4.60)
Excessive/persistent use	43 (17.6)	59 (24.5)	32 (28.1)	1.74 (0.97–3.09)	2.47 (1.16–5.25)
Lifetime smartphone exposure					
Lower exposure	64 (26.2)	48 (19.7)	17 (14.9)	1.00 (reference)	1.00 (reference)
Intermediate exposure	78 (32.0)	63 (25.8)	28 (24.6)	1.01 (0.60–1.70)	1.39 (0.67–2.87)
Higher exposure	61 (25.0)	68 (27.9)	33 (29.0)	1.22 (0.72–2.08)	1.78 (0.85–3.69)
Extreme exposure	41 (16.8)	65 (26.6)	36 (31.6)	1.68 (0.95–2.97)	2.95 (1.39–6.27)

[a]ORs and 95% CIs calculated using multinomial logistic regression models adjusted for sex, age, sleep duration, use of contact lenses, computer use and city. For participants excluding contact lens users, ORs and 95% CIs calculated using multinomial logistic regression models adjusted for sex, age, sleep duration, computer use and city.
[b]Analysis performed with total participants and participants excluding contact lens users.
OR, odds ratio; CI, confidence interval.

electromagnetic fields (EMFs); extremely low frequency EMFs and radiofrequency (RF) electromagnetic radiation (EMR).[15,16] We can consider the effects of smartphones on the eyes as a kind of computer vision syndrome, which is the group of ocular problems associated with the use of electronic devices.[17] We view the increase of ocular symptoms in adolescents as computer vision syndrome extended to the general population, especially in adolescents, after the expansion of smartphone use. The intensity of radiation from mobile phones is relatively low with a specific absorption rate <4 W/kg.[16,18,19] However, it has been reported that adverse effects, such as DNA damage and thickening of the cornea, occurs even at a specific absorption rate lower than 4 W/kg.[16,20–22] Moreover, it has been shown that the local specific absorption rate is higher in tissues at a younger age, which could explain the higher susceptibility of adolescents to smartphones.[10]

The EMFs generated by smartphones may interact with the tissues of the eyes.[15,23] EMFs are reported to cause apoptosis, cataract formation, edema, endothelial cell loss, inflammatory responses and neurological effects.[16,19–21,24,25] Extremely low frequency EMFs are reported to induce electric fields and currents, which may interact with human tissue.[15] RF EMR as the other mechanism, affects the body thermally and non-thermally.[26] The eye is an organ that is directly exposed and susceptible to RF EMR because it is located relatively exteriorly,[20,27] and is among the most vulnerable organs to heat in the body because of a low blood supply.[28,29] RF EMR derived from mobile phones has been shown to increase facial nerve dysfunction and cancer such as uveal melanoma and cause changes in protein conformation, protein expression, receptor function and attraction between cells.[18,26,30–32] In addition, non-thermal effects of RF electric fields could have an effect on the eyes. It has been reported that radiation from mobile phones causes oxidative stress in the cornea and the lens.[19] These effects by EMFs and RF EMR on the eyes, especially on the cornea and the lens, could suggest why ocular symptoms such as blurring, redness, visual disturbance, inflammation and lacrimation increased when exposed to smartphones.

Our study has the following limitations. First, because information was only collected by questionnaire, information biases could not be excluded.[33] Participants were likely to be aware of the study questions under investigation, therefore the possibility of recall bias could not be excluded. Second, our study is susceptible to reverse causality because it is of cross-sectional design. Third, because the questionnaire was self-administered, although with written instructions, without assistance from the research team on-site, the validity of the obtained data could be low. Fourth, because the symptoms were self-reported by the

subjects rather than diagnosed by a physician, it could have caused misclassification in our results. Fifth, we used a questionnaire that was used in two previous studies which was not a validated ocular symptom questionnaire such as the Ocular Surface Disease Index for the assessment of severity of dry eye disease.[34]

Nonetheless, our study has the following merits. Our subjects were from three different regions in Korea, which could reduce the risk of selection bias resulting from recruiting subjects from only one city. We were able to evaluate various ocular symptoms related to computer vision syndrome other than dryness of the eyes by devising our own questionnaire rather than using a questionnaire that was already made for a different study for a different purpose. Our study is one of the first to show the association between the effects of smartphones and ocular symptoms, to elucidate their risk factors and to suggest proper guidelines for using smartphones.

This study has shown that longer smartphone use increases the likelihood of multiple ocular symptoms. Therefore, smartphones should be used with caution, and understanding the factors of smartphone use that account for the risk of ocular symptoms could help the growing population of smartphone users to use smartphones in a healthier manner. However, it is important to note that smartphone use is not a health hazard in itself, but its overuse may be. Although multiple ocular symptoms do not mean pathological changes in the eyes, we suggest that adolescent smartphone users limit the use of smartphones to <2 hours/day. The authors hope that this study leads to insightful clinical implications and that it encourages further studies including larger scale longitudinal studies, and research on the mechanism focused on pathologic changes in the eye.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the writing and content of this article.

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