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Association of smartphone use with abnormal social jetlag among adolescents in Korea before and after COVID-19

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ABSTRACT

Purpose: This study aimed to use social jetlag to determine how smartphone overuse by adolescents before and after the COVID-19 pandemic might be associated with their circadian rhythm.
Methods: We used 2017 and 2020 Korea Youth Risk Behavior web-based Survey data and conducted a survey analysis on 100,976 adolescents. The dependent variable was abnormal social jetlag. Based on the times recorded by the survey, we calculated the weekday midpoint and weekend sleep time. The main independent variable was smartphone usage time (<2h/day, 2–3.9 h/day, 4–5.9 h/day, and ≥ 6 h/day). Multiple logistic regression and relative excess risk due to interaction (RERI) were performed.
Results: Abnormal social jetlag was most prevalent in male and female adolescents who used smartphones ≥ 6 h/day (adjusted odds ratio [AOR] = 2.60, 95 % confidence interval [CI] = 2.47–2.74). The longer the smartphone usage time, the higher the association with abnormal social jetlag. This association was more prominent in female adolescents. The additive interaction between longer smartphone usage time and post-COVID-19 year was statistically significant (total: RERI = 0.92, 95 % CI = 0.90–0.95; males: RERI = 0.83, 95 % CI = 0.80–0.87; females: RERI = 1.13, 95 % CI = 1.08–1.18).
Conclusion: Our results clearly indicated that increased smartphone usage time tended to result in greater social jetlag, an association that was more pronounced in female. Moreover, the COVID-19 pandemic significantly strengthened this relationship. Further research is needed regarding the proper use of smartphones to ensure good sleep-in adolescents after the COVID-19 pandemic.

1. Introduction

Recently, smartphones have penetrated deeply into our daily lives. In Korea, >90 % of people own a smartphone (Silver, 2019). Smartphones have enriched human life by providing information and enhancing social connectivity and entertainment (Oviedo-Trespalacios, Nandavar, Newton, Demant, & Phillips, 2019). However, inappropriate smartphone usage is detrimental to both physical and mental health (Yang, Fu, Liao, & Li, 2020). According to one survey in Korea, 19.3 % of the total population are potential risk users for smartphone overdependence, and 4.0 % are high-risk users (Kim & Lee, 2022). Moreover, as non-face-to-face classes and indirect social interactions have increased after the COVID-19 pandemic, the time spent using media, including smartphones, has increased (Caponnetto et al., 2021).

This overuse of smartphones can lead to physical problems such as fatigue, a weakened immune system, and cancer, as well as various mental health problems including reduced self-regulation and increased obsessive behavior and anxiety (Demirci, Akgönül, & Akpinar, 2015; Johansen, Boice, McLaughlin, & Olsen, 2001; Thomée, Härenstam, & Hagberg, 2011). In addition, smartphone overuse is associated with the

Abbreviations: AOR, adjusted odds ratio; CI, confidence interval; KCDA, Korea Disease Control and Prevention Agency; KYRBS, Korea Youth Risk Behavior web-based Survey; RERI, relative excess risk due to interaction; LEDs, light-emitting diodes.

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length and quality of sleep, and studies have shown that the sleep quality and daytime dysfunction score are lower in the group with a higher smartphone usage time (Lin et al., 2014).

Although some studies related smartphone overuse to sleep-related problems, there are few studies on the association with social jetlag, defined as the gap in sleep time between weekdays and weekends (Touitou, Touitou, & Reinberg, 2016). Social jetlag refers to the misalignment of biological and social time (Wittmann, Dinich, Merrow, & Roenneberg, 2006). Social jetlag can be determined by calculating the difference between the midpoints of weekday and weekend sleep times. Greater social jetlag would mean that there is a larger difference between the weekday and weekend sleep time (i.e., sleep and wake times) (Cespedes Feliciano et al., 2019).This means that the difference between the circadian rhythm and the social cycle is large (Chang & Jang, 2019). For example, individuals with a naturally late chronotype should adapt to an early social routine, which tends to increase sleep debt during the week and compensates for it on the weekend. Thus, social jetlag may be intended for individuals to adapt to chronotype and school or work schedules and is usually determined within a 2- hour period (Johnson et al., 2020).

Previous studies have shown an association of social jetlag with metabolic disorders and mental distress (Levandovski et al., 2011; Malone et al., 2016; Rutters et al., 2014). Moreover, female adolescents show a greater correlation between social jetlag and depression and severe menstrual symptoms (Komada et al., 2019; Mathew, Hale, & Chang, 2019; Mathew, Li, Hale, & Chang, 2019). Therefore, it is important to identify and intervene by controlling the factors related to social jetlag. In particular, Korean adolescents who are accustomed to going to school early and attending in night school or engaging in after-school activities at private educational institutions often until 21:00–24:00 (Kang et al., 2014; Lee, Cho, Cho, & Kim, 2012) tend to recover the lack of sleep on the weekend; thus, resolving social jetlag is an important public health issue. By identifying the factors associated with social jetlag in Korean adolescents, it would be possible to improve both physical and mental quality of life by implementing appropriate strategies.

The aim of this study was to determine the relationship between smartphone usage and social jetlag in Korean adolescents. In addition, we hypothesized that there is a relationship difference between the two indicators as the non-face-to-face class method has expanded due to the COVID-19 pandemic, thereby increasing the smartphone usage time and partially changing the early school hours previously maintained in face-to-face living. Therefore, we investigated the interaction between smartphone usage and year (before and after COVID-19) and social jetlag to analyze the effect of COVID-19 on adolescents' lives and circadian rhythm.

2. Methods

2.1. Study population and data

We used the data obtained from the Korea Youth Risk Behavior web-based Survey (KYRBS), which conducted surveys on a nationally representative sample of South Korean adolescents attending middle and high school (grades 7–12, age 12–18). For this cross-sectional study, we used data from the 2017 and 2020 surveys as they contained questions relevant to the study. The KYRBS was initiated by the Korean Ministry of Education, Ministry of Health and Welfare, and Korea Disease Control and Prevention Agency (KCDA) in 2005. Ethical approval for KYRBS was waived by the Institutional Review Board of the KCDA in accordance with the Bioethics and Safety Act of 2015 (Kim, Jeong, Park, & Jang, 2021; Koo et al., 2021).

The KYRBS is an anonymous self-administered structured questionnaire that uses a complex research design of multistage sampling, stratification, and clustering to obtain a nationally representative sample. All participants voluntarily log in using their certificate number and check the online informed consent themselves (Kim, Lee, Lee, Jo, & Kim, 2020). Participants cannot move on to the next section unless all the questions from the current section are answered, although responses with logical errors and responses that are outliers are treated as missing data.

The question, "On average, how many hours per day do you use your smartphone?" was included in the KYRBS 2017 and 2020. Therefore, data from only these years were analyzed. The total number of students participating in KYRBS 2017 and 2020 was 117,224 (59,977 [51.2 %] males and 57,247 [48.8 %] females). Among them, participants with missing data due to logical errors or outliers in sleeping and waking times (missing data of sleeping and waking times on weekdays: n = 15,992; missing data of sleeping and waking times on weekend: n = 256) were excluded from the analysis. As a result, a total of 100,976 participants (51,312 [50.8 %] males and 49,664 [49.2 %] females) were included in the study (Fig. 1).

2.2. Variables

The main dependent variable in this study was social jetlag. The average sleep duration on weekdays and weekends was assessed by the question "During the past 7 days, what time did you usually go to bed and wake up?" In response to this question, the participants recorded the time they went to bed and the time they woke up on weekdays and weekends, respectively. Based on the recorded times, we calculated the midpoint of weekday and weekend sleep times and determined the difference to assess if the subject had an abnormal social jetlag. Social jetlag was calculated using the formula (weekend sleep time midpoint) - (weekday sleep time midpoint) (Díaz-Morales & Escribano, 2015; Parsons et al., 2015; Wittmann et al., 2006). A commonly used standard to categorize abnormal and normal social jetlag is not available; however, based on previous studies, our study categorized < 2 h of social jetlag as normal and>2 h as abnormal (Kim & Kim, 2020).

The main independent variable was smartphone usage time. In 2020, it was calculated using the question "During the past 7 days, how many hours a day did you use your smartphone on average?" In 2017, it was calculated using the question "During the past 30 days, how many hours a day did you use your smartphone on average?" In response to this question, the participants first chose whether they used their phone or not and then recorded the time they used their phones on weekdays and weekends, respectively. Based on the recorded times, the average smartphone usage time on weekdays and weekends was calculated. Finally, smartphone usage time was divided into < 2 h/day, 2–3.9 h/day, 4–5.9 h/day, and ≥ 6 h/day.

Other independent variables affecting social jetlag were also considered as covariates. They included the year (2020 and 2017; more specifically, before and after the COVID-19 pandemic); average weekday and weekend sleep durations (<6.9 h, 7 h ≤ duration < 8.9 h, 9 h ≤ duration); subjective sleep quality (bad, good); school year (7th–12th); economic status (low, medium–low, medium, medium–high, or high); residence type (with family, with relative, or without family or relative); academic achievement (low, medium–low, medium, medium–high, or high); alcohol status (ever or never); smoking status (everyday, someday, or never); physical activity (low or high, with high indicating > 20 min of intense physical activity and > 60 min of physical activity to the extent of shortness of breath ≥ 3 days per week); self-reported health status (low, medium, or high); and perception of stress (low, medium, or high).

2.3. Statistical analyses

Chi-squared tests were used to evaluate differences in the frequency and proportion of categorical variables. We performed a multiple logistic regression analysis after adjusting for covariates to analyze the association of smartphone usage time and abnormal social jetlag. Subgroup analysis was performed to examine the relation according to the

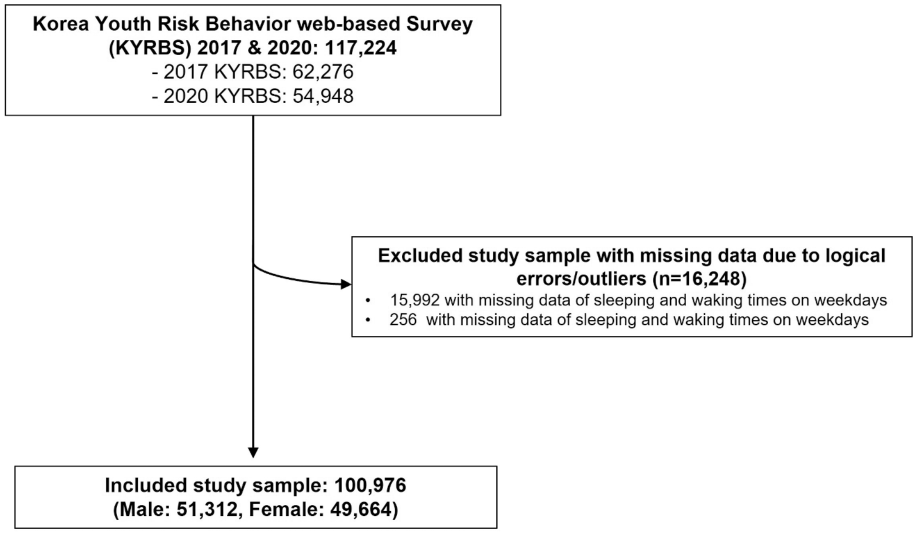


Fig. 1. Flow chart for study sample.

proportion of smartphone usage time on weekdays and weekends even if the smartphone usage hours were the same. Furthermore, we employed relative excess risk due to interaction (RERI) to investigate the presence of interactions on an additive scale of whether the combination of smartphone usage time and post-COVID-19 period posed a greater risk than the sum of their independent effects. RERI was calculated as the difference between the expected value based on the addition of the odds ratios of the two separate risk factors and the observed value in the dually exposed group (Kim, Hurh, Park, Jang, & Park, 2021), where RERI > 0 indicated a synergistic effect with increased smartphone usage time and the year post-COVID-19. Multiple logistic regression was used to performed stratified analyses by sex and year. Finally, we split the dependent subgroup according to different social jetlag thresholds for sensitivity analysis. All statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC, USA), and a weighted logistic regression procedure was conducted to account for the complex and stratified sampling design of the KYRBS. Two-sided significance threshold of $P < 0.05$ was considered statistically significant.

3. Results

Table 1 presents the general characteristics of study sample. Of the 100,976 participants, 41,672 (41.3 %) showed abnormal social jetlag. The rate of abnormal social jetlag was higher among those who used smartphones > 6 h/day (57.4 %, $n = 12{,}335$) than among those who used smartphones for < 2 h (29.7 %), 2–3.9 h (35.8 %) and 4–5.9 h/day (46.3 %). In 2020, the rate of abnormal social jetlag (41.6 %, $n = 20{,}867$) was higher in adolescents compared to that in 2017 (35.3 %, n = 20,805).

Table 2 shows the adjusted odds ratio (AOR) of factors associated with abnormal social jetlag. The odds of abnormal social jetlag increased as the smartphone usage time increased. Participants who used their smartphones for>6 h a day demonstrated the highest risk of abnormal social jetlag than those who used smartphones<2 h a day (AOR = 2.60, 95 % CI = 2.47–2.74). Compared to 2017, before the outbreak of COVID-19, there were higher odds of abnormal social jetlag in 2020 (AOR = 1.19, 95 % CI = 1.14–1.24). Additionally, participants with “bad” subjective sleep quality, alcohol intake, or smoking were more likely to experience abnormal social jetlag.

Table 3 describes the subgroup analyses of the association between smartphone usage time and abnormal social jetlag, focusing on the difference between smartphone usage time on weekends and weekdays. Adolescents who used their smartphones > 4 h/day, with a higher smartphone usage time during the weekends, showed higher abnormal social jetlag than those with a higher smartphone usage time during the weekdays.

Table 4 shows the results of the stratified analyses. Abnormal social jetlag reported prominent associations with increased smartphone usage time among female adolescents (male: smartphone use ≥ 6 h/day, AOR = 2.08, 95 % CI = 1.94–2.23; female: smartphone use ≥ 6 h/day, AOR = 3.24, 95 % CI = 3.00–3.50). Moreover, year 2020 reported a prominent association between increased smartphone usage and abnormal social jetlag (year 2017: smartphone use ≥ 6 h/day, AOR = 2.39, 95 % CI = 2.23–2.57; year 2020: smartphone use ≥ 6 h/day, AOR = 3.01, 95 % CI = 2.77–3.27).

Table 5 presents the sensitivity analysis of the association between smartphone usage time and abnormal social jetlag according to different social jetlag thresholds. The results were similar even when the abnormal social jetlag was set to 1, 2, 3, and 4 h. Thus, the probability of having abnormal social jetlag gradually increased as the smartphone usage time increased.

Fig. 2 presents synergistic interactions of smartphone usage time and year of post COVID-19 pandemic with abnormal social jetlag on an additive scale. The graphs show that the absolute difference between high usage time and low usage time was greater during the COVID-19 pandemic (2020) than before the pandemic. The RERI showed that when increased smartphone usage time and the outbreak of COVID-19 were present together, the odds ratio was greater than the sum of the individual effects.

4. Discussion

This study provides evidence that a long smartphone usage time is associated with abnormal social jetlag in Korean adolescents. The association between smartphone usage time and abnormal social jetlag demonstrated a progressively increasing pattern as the smartphone usage time increased. Smartphones are one of the main sources of light-emitting diode (LED) exposure for adolescents. LED exposure affects biological clocks (Dai et al., 2016). Especially in adolescents, pre-sleep LED exposure causes phase delay and slowing of melatonin secretion (Chang, Aeschbach, Duffy, & Czeisler, 2014), higher alertness, and decreased sleepiness (Grønli et al., 2016). In addition, differences in smartphone usage goals on weekdays and weekends can also explain our results (Woo, Bong, Choi, & Kim, 2021).

The association between smartphone usage time and abnormal social jetlag was prominent in female adolescents. In adolescents, smartphone-

Table 1
General characteristics of the study subjects.

Variables	Social jet lag: Total N	Abnormal (≥2h) N	Abnormal (≥2h) %	Normal (<2hr) N	Normal (<2hr) %	*P*-value
	100,976	**41,672**	**41.3**	**59,304**	**58.7**	
Smartphone usage time						<0.0001
<2 h/day	23,818	7,080	29.7	16,738	70.3	
2–3.9 h/day	33,588	12,033	35.8	21,555	64.2	
4–5.9 h/day	22,087	10,224	46.3	11,863	53.7	
≥6 h/day	21,483	12,335	57.4	9,148	42.6	
Year						<0.0001
2017	54,607	20,805	35.3	33,802	64.7	
2020	46,369	20,867	41.6	25,502	58.4	
Sleep duration (h)[a]						<0.0001
<7	52,429	20,270	38.7	32,159	61.3	
7–8.9	40,119	16,275	40.6	23,844	59.4	
≥9	8,428	5,127	60.8	3,301	39.2	
Subjective sleep quality						<0.0001
Bad	72,966	31,538	43.2	41,428	56.8	
Good	28,010	10,134	36.2	17,876	63.8	
Sex						
Male	51,312	19,648	38.3	31,664	61.7	
Female	49,664	22,024	44.3	27,640	55.7	
School year						<0.0001
7th	17,215	6,302	36.6	10,913	63.4	
8th	16,714	6896	36.1	9,818	58.7	
9th	16,554	7,198	43.5	9,356	56.5	
10th	16,581	7,290	44.0	9,291	56.0	
11th	17,199	7,502	43.6	9,697	56.4	
12th	16,713	6,484	38.8	10,229	61.2	
Economic status						<0.0001
Low	2,322	1,134	48.8	1,188	51.2	
Medium-low	11,385	5,298	46.5	6,087	53.5	
Medium	47,510	20,489	43.1	27,021	56.9	
Medium-high	29,091	10,899	37.5	18,192	62.5	
High	10,668	3,852	36.1	6,816	63.9	
Residence type						<0.0001
Live w/o family or relative	4,257	1,565	36.8	2,692	63.2	
Live with relative	582	289	49.7	293	50.3	
Live with family	96,137	39,818	41.4	56,319	58.6	
Academic achievement						<0.0001
Low	9,395	5,133	54.6	4,262	45.4	
Medium-low	22,699	10,849	47.8	11,850	52.2	
Medium	29,834	12,295	41.2	17,539	58.8	
Medium-high	25,794	9,225	35.8	16,569	64.2	
High	13,254	4,170	31.5	9,084	68.5	
Alcohol status						<0.0001
Ever	36,516	17,352	47.5	19,164	52.5	
Never	64,460	24,320	37.7	40,140	62.3	
Smoking status						<0.0001
Everyday	3,364	1,992	59.2	1,372	40.8	
Some day	8,003	3,941	49.2	4,062	50.8	
Never	89,609	35,739	39.9	53,870	60.1	
Physical activity						<0.0001
Low	57,624	24,693	42.9	32,931	57.1	
High	43,352	16,979	39.2	26,373	60.8	
Self-Reported Health Status						<0.0001
Low	6,777	3,135	46.3	3,642	53.7	
Medium	22,074	9,607	43.5	12,467	56.5	
High	72,125	28,930	40.1	43,195	59.9	
Perception of stress						<0.0001
Low	21,199	8,424	39.7	12,775	60.3	
Medium	43,983	18,007	40.9	25,976	59.1	
High	35,794	15,241	42.6	20,553	57.4	

Bold indicate the total number of study participants.
[a] Average sleep duration of weekday and weekend.

Table 2
Factors associated with abnormal social jet lag.

Variables	Abnormal social jet lag (≥2 hr): AOR	95 % CI
Smartphone usage time		
<2 h/day	**1.00**	
2–3.9 h/day	1.26	(1.20 – 1.31)
4–5.9 h/day	1.81	(1.73 – 1.90)
≥6 h/day	2.60	(2.47 – 2.74)
Year		
2017	**1.00**	
2020	1.19	(1.14 – 1.24)
Sleep duration (h) [a]		
<7	0.71	(0.68 – 0.73)
7–8.9	**1.00**	
≥9	2.99	(2.81 – 3.18)
Subjective sleep quality		
Bad	1.46	(1.41 – 1.52)
Good	**1.00**	
Sex		
Male	**1.00**	
Female	1.46	(1.41 – 1.52)
School year		
7th	0.90	(0.84 – 0.96)
8th	1.05	(0.99 – 1.12)
9th	1.15	(1.08 – 1.22)
10th	1.30	(1.23 – 1.37)
11th	1.20	(1.13 – 1.26)
12th	**1.00**	
Economic status		
Low	1.08	(0.97 – 1.20)
Medium-low	1.16	(1.08 – 1.24)
Medium	1.08	(1.02 – 1.14)
Medium-high	0.98	(0.93 – 1.03)
High	**1.00**	
Residence type		
Live w/o family or relative	**1.00**	
Live with relative	1.54	(1.24 – 1.91)
Live with family	1.17	(1.04 – 1.31)
Academic achievement		
Low	1.84	(1.72 – 1.97)
Medium-low	1.50	(1.42 – 1.58)
Medium	1.28	(1.21 – 1.34)
Medium-high	1.09	(1.04 – 1.15)
High	**1.00**	
Alcohol status		
Ever	1.34	(1.30 – 1.39)
Never	**1.00**	
Smoking status		
Everyday	1.66	(1.51 – 1.83)
Some day	1.22	(1.15 – 1.29)
Never	**1.00**	
Physical activity		
Low	1.09	(1.06 – 1.13)
High	**1.00**	
Self-Reported Health Status		
Low	**1.00**	
Medium	0.94	(0.88 – 1.00)
High	0.94	(0.88 – 0.99)
Perception of stress		
Low	1.13	(1.08 – 1.18)
Medium	1.05	(1.01 – 1.08)
High	**1.00**	

Bold type means referance group.
Abbreviations: AOR, adjusted odds ratio; CI, Confidence Interval.
[a] Average sleep duration of weekday and weekend.

related problems may appear differently depending on the sex (Lee et al., 2018), with female adolescents being more prone to smartphone addiction (Randler et al., 2016). The smartphone addiction susceptibility of females may have influenced the abnormal social jetlag. Furthermore, the effect of light sensitivity on sleep differs according to sex (Chellappa, Steiner, Oelhafen, & Cajochen, 2017), and even when the sleep duration is the same, the circadian rhythm of core body temperature and the pineal melatonin secretion are faster in females than in

Table 3
Sub-group analysis of the association between smartphone usage time and abnormal social jetlag emphasizing the difference between smartphone usage time on weekends and weekdays.

Variables	Abnormal social jet lag (≥2h)	
	AOR	95 % CI
Smartphone usage time		
<2 h/day	**1.00**	
2–3.9 h/day		
Weekday ≥ Weekend	1.11	(1.00 – 1.24)
Weekday < Weekend	1.27	(1.22 – 1.33)
4–5.9 h/day		
Weekday ≥ Weekend	1.32	(1.15 – 1.52)
Weekday < Weekend	1.86	(1.77 – 1.95)
≥6h/day		
Weekday ≥ Weekend	1.76	(1.55 – 1.99)
Weekday < Weekend	2.71	(2.57 – 2.86)

AORs are adjusted for all covariates.
Abbreviations: AOR, adjusted odds ratio; CI, Confidence Interval.

males (Cain et al., 2010). Therefore, biological differences may have led to this result; however, further studies are needed to elucidate this phenomenon.

Since the COVID-19 outbreak, the gradient of increasing the odds of abnormal social jetlag has steepened owing to the increase in smartphone usage time. After the outbreak of COVID-19 pandemic, online classes were conducted in Korean schools. The resulting change in life pattern may have led to these results. Regular aerobic exercise helps keep the biological clock constant (Hower, Harper, & Buford, 2018), and daytime activity increases the depth and quality of night-time sleep (Trinder, Montgomery, & Paxton, 1988). Before COVID-19, students had to walk to and from school and had to participate in physical activities at school. When online classes progressed, it became increasingly difficult for schools to encourage and induce students' physical activities. Therefore, even if adolescents wake up to take classes on weekdays, there is no physical activity; hence, the degree of awakening is low, and maintaining the circadian rhythm may become more difficult as regular exercise, which is known to control sleep patterns, decreases. As a result, after the outbreak of the COVID-19 pandemic, the use of smartphones had a greater impact on the occurrence of abnormal social jetlag. Furthermore, the cancellation of club practices and reduced social activities due to social distancing that has been implemented since the COVID-19 pandemic are also related to the lack of physical activity among adolescents (Yomoda & Kurita, 2021). Decreased physical activity, as well as increased sedentary lifestyle and screen exposure, have been associated with changes in sleep patterns since the COVID-19 pandemic (Bruni et al., 2022). Although we adjusted for moderate or high intensity physical activity in this study, we could not consider changes in light physical activity in daily life. Taken together, it is possible that changes in life patterns after COVID-19 pandemic have strengthened the association between smartphone use and abnormal social jetlag. Another possibility is that fear and psychological anxiety about COVID-19 were involved in the additive interaction (Siddique, Ahmed, & Hossain, 2021).

Notably, even if the average daily smartphone usage time was the same, adolescents who spent more time to use smartphone on weekends than on weekdays were more likely to experience abnormal social jetlag. These results are likely due to the following reasons: Adolescents who spend a lot of time on weekdays and adolescents who spend a lot of time on weekends may have different purposes for using smartphones. Smartphones are mainly used for social networking service (SNS), games, or video viewing (Cha & Seo, 2018). However, the LED exposure may be different when using SNS and when playing games with a smartphone. In other words, adolescents who use their smartphones longer on weekends may be exposed to more LEDs. Further research is needed to determine the exact cause and set the direction of intervention.

In this study, we defined abnormal social jetlag as a case where the midpoint difference was>2 h. The criterion for abnormality when the range of social jetlag exceeds a certain level is not clear. However, the reason why we set social jetlag of<2 h as the normal range is that many

Table 4
Stratified analyses by sex and year.

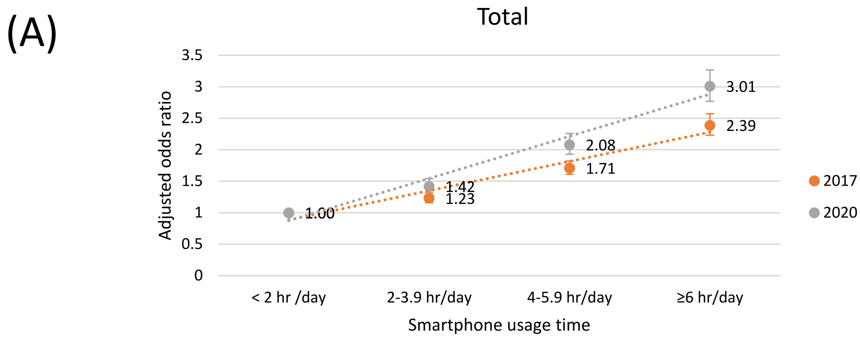
Variables	Abnormal social jet lag (≥2h)						
	<2 h/day	2–3.9 h/day		4–5.9 h/day		≥6h/day	
	AOR	AOR	95 % CI	AOR	95 % CI	AOR	95 % CI
Sex							
Male	**1.00**	1.25	(1.18 – 1.32)	1.59	(1.49 – 1.69)	2.08	(1.94 – 2.23)
Female	**1.00**	1.32	(1.22 – 1.41)	2.14	(1.99 – 2.30)	3.24	(3.00 – 3.50)
Year							
2017 (Before COVID-19)	**1.00**	1.23	(1.16 – 1.29)	1.71	(1.61 – 1.82)	2.39	(2.23 – 2.57)
2020 (After COVID-19)	**1.00**	1.42	(1.32 – 1.54)	2.08	(1.93 – 2.26)	3.01	(2.77 – 3.27)

Bold type means referance group.
Abbreviations: AOR, adjusted odds ratio; CI, Confidence Interval.
AORs are adjusted for all covariates.

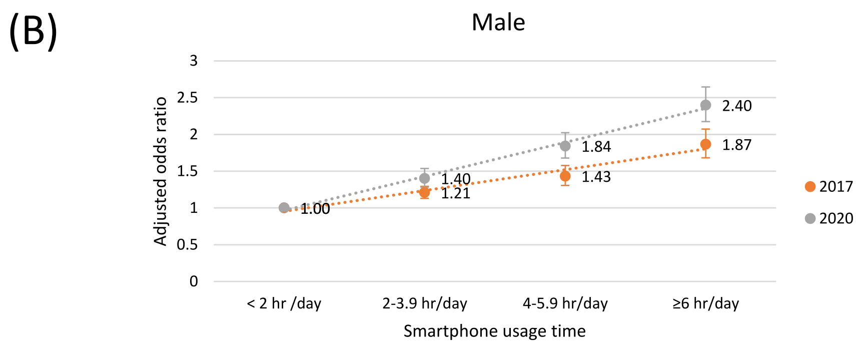
Table 5
Sensitivity analysis of the association between smartphone usage time and abnormal social jetlag according to different social jetlag thresholds.

Variables	Social jet lag							
	≥1 h		≥2 h		≥3 h		≥4 h	
	AOR	95 % CI	AOR	95 % CI	AOR	95 % CI	AOR	95 % CI
Smartphone usage time								
<2 h/day	**1.00**		**1.00**		**1.00**		**1.00**	
2–3.9 h/day	1.43	(1.37 – 1.49)	1.26	(1.20 – 1.31)	1.07	(1.01 – 1.13)	0.94	(0.86 – 1.00)
4–5.9 h/day	1.97	(1.87 – 2.08)	1.81	(1.73 – 1.90)	1.55	(1.46 – 1.65)	1.31	(1.20 – 1.42)
≥6 h/day	2.68	(2.53 – 2.85)	2.60	(2.47 2.74)	2.41	(2.27 – 2.56)	2.20	(2.02 – 2.40)

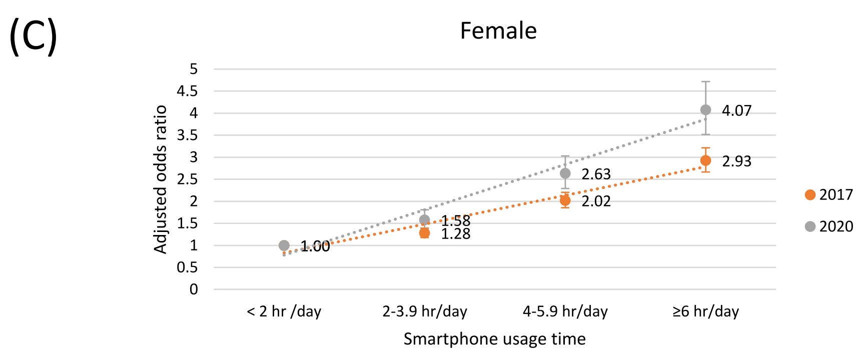
Bold type means referance group.
Abbreviations: AOR, adjusted odds ratio; CI, Confidence Interval.
AORs are adjusted for all covariates.



Smartphone usage time	Abnormal social jet lag (≥ 2 hr) Year (2017) :Before COVID-19 AOR	95% CI	Year (2020): After COVID-19 AOR	95% CI	Multiplicative interaction, p	RERI (95% CI)
< 2 h /day	1.00		1.00			
2 - 3.9 h /day	1.23	(1.16–1.29)	1.42	(1.32–1.54)	<0.001	0.92 (0.90 – 0.95)
4 - 5.9 h /day	1.71	(1.61–1.82)	2.08	(1.93–2.26)		
≥ 6 h /day	2.39	(2.23–2.57)	3.01	(2.77–3.27)		



Smartphone usage time	Abnormal social jet lag (≥ 2 hr) Year (2017) :Before COVID-19 AOR	95% CI	Year (2020): After COVID-19 AOR	95% CI	Multiplicative interaction, p	RERI (95% CI)
< 2 h /day	1.00		1.00			
2 - 3.9 h /day	1.21	(1.13–1.30)	1.40	(1.28–1.54)	<0.001	0.83 (0.80 – 0.87)
4 - 5.9 h /day	1.43	(1.31–1.58)	1.84	(1.68–2.02)		
≥ 6 h /day	1.87	(1.68–2.07)	2.40	(2.17–2.64)		



Smartphone usage time	Abnormal social jet lag (≥ 2 hr) Year (2017) :Before COVID-19 AOR	95% CI	Year (2020): After COVID-19 AOR	95% CI	Multiplicative interaction, p	RERI (95% CI)
< 2 h /day	1.00		1.00			
2 - 3.9 h /day	1.28	(1.18–1.40)	1.58	(1.37–1.81)	<0.001	1.13 (1.08 – 1.18)
4 - 5.9 h /day	2.02	(1.85–2.20)	2.63	(2.29–3.03)		
≥ 6 h /day	2.93	(2.66–3.21)	4.07	(3.52–4.72)		

Fig. 2. Interactions between smartphone usage time and COVID-19 in relation to social jetlag on additive scale. AOR, adjusted odds ratio; CI, confidence interval; RERI, relative excess risk due to interaction.

previous studies have reported a high association with diseases such as depression or metabolic syndrome when social jetlag exceeds 2 h in adolescents (Islam et al., 2018; Levandovski et al., 2011; Tamura, Komada, Inoue, & Tanaka, 2022). Furthermore, through sensitivity analysis, when the abnormal range of social jetlag was defined as 1 h or more (when the standard was lowered), the association between smartphone usage time and abnormal social jetlag was higher, confirming that our results were robust.

This study has several strengths that differentiate it from previous studies on adolescent smartphone use. First of all, as this cross-sectional study was used national survey data with 100,976 participants based on random cluster sampling, our results were sufficiently representative of Korean adolescents (Lee, Kim, Jeon, Kim, & Park, 2022). Furthermore, to increase the reliability and accuracy of the study, many covariates related to smartphone use and social jetlag were considered. Finally, we found that the COVID-19 pandemic contributes to amplifying associations with abnormal social jetlag, even for the same amount of smartphone use using RERI. Because additive interactions have a higher absolute excess of cases than multiplicative interactions, it is very important to estimate additive measures in terms of public health interventions (Kim, Hurh, et al., 2021; Knol & VanderWeele, 2012). Our study responds to the concern that excessive use of devices such as smartphones by adolescents will affect circadian rhythms and related health conditions more than usual in outbreaks such as COVID-19.

Despite many strengths, our study had some limitations. First, the study's cross-sectional design did not allow us to clearly identify the direction of the association of smartphone usage time with abnormal social jetlag. Second, the results of this study were based on anonymous self-reported data. Thus, subjective sleep quality might have been underestimated or overestimated, and some survey questions might be subject to recall bias. Third, missing data occurred due to logical errors and outliers regarding sleep or wake up time on weekends and weekdays, and these participants could not be included in the study. Forth, the survey questions used to assess the independent variable, i.e., smartphone usage time, differed between 2020 and 2017. It is assumed that the change in the questionnaire is part of an effort to reduce the recall bias. Despite these limitations, we had no choice but to use this variable as it was the only means for comparison of variables before and after the COVID-19 outbreak. Lastly, the survey question did not categorize the purpose of smartphone usage, because the KYRBS did not assess that information.

5. Conclusions

In conclusion, our study demonstrated that Korean adolescents are significantly more likely to have abnormal social jetlag if they have a higher smartphone usage time. This association was more prominent in female adolescents. Furthermore, our results provided further evidence that the concomitant increased smartphone usage time and the outbreak of COVID-19 may be synergistically associated with abnormal social jetlag in Korean adolescents. Further studies are warranted to identify the biological or sociological reasons that make females more prone to abnormal social jetlag than males. Simultaneously, policy makers, parents, and schools need to consider appropriate education and interventions that can help control smartphone usage to improve adolescents' abnormal social jetlag after the COVID-19 pandemic.

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CRediT authorship contribution statement

Yerin Cho: Conceptualization, Data curation, Formal analysis, Visualization, Writing – original draft. **Heewon In:** Conceptualization, Data curation, Formal analysis, Visualization, Writing – original draft. **Minseo Park:** Conceptualization, Data curation, Formal analysis, Visualization, Writing – original draft. **Eun-Cheol Park:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Seung Hoon Kim:** Conceptualization, Methodology, Formal analysis, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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