

Sleep loss among Thai high school students smartphone users affected by smartphone electromagnetic pollution

Sleep loss

317

Time series study

Wanna Chongchitpaisan and Phongtape Wiwatanadate

*Department of Community Medicine,
Chiang Mai University, Chiang Mai, Thailand*

Assawin Narkpongphun

Department of Psychiatry, Chiang Mai University, Chiang Mai, Thailand

Surat Tanprawate

*Department of Internal Medicine,
Chiang Mai University, Chiang Mai, Thailand, and*

Nipapon Siripon

Chiang Mai University, Chiang Mai, Thailand

Received 11 May 2019

Revised 1 July 2019

6 August 2019

Accepted 27 August 2019

Abstract

Purpose – Adolescents being in a stage of growth need good sleep, but, today, they suffer from sleep deprivation due to such extrinsic factor as a smartphone which they enjoy spending time using the device. However, the effects of smartphone output power (SOP) on the duration of good sleep remains unclear. The purpose of this paper is to investigate the correlation of the SOP and sleep loss in high school students.

Design/methodology/approach – The time-series study was conducted among 145 high school students in Chiang Mai Province who completed a sleep diary which applied by the Pittsburg Sleep Quality Index. The SOP was corrected by a smartphone application and transmitted by e-mail to a researcher every day. The completed data set contains 12,969 entries. Headache, anxiety and depression were also assessed. Data were analyzed using the generalized estimating equation adjusted for demographic data, smartphone use and other factors.

Findings – Most of the study subjects are female, 17.4 years old on average. The prevalence of sleep loss (< 8 h) was 52.9 percent with averagely 7.4 ± 1.7 h of sleep duration and poor sleep at 32.1 percent. Anxiety, depression, headache had relationships with sleep loss. The daily dose, evening and nocturnal SOP in the range of $\geq 2.00 \times 10^{-5}$ mW had stronger relationships with sleep loss than their effects in the range of $\leq 1.79 \times 10^{-5}$ mW (OR_{adj}1.32; 95% CI: 1.26–1.76, OR_{adj}1.34; 95% CI: 1.07–1.17 and OR_{adj}1.41; 95% CI: 1.07–1.17, respectively). Meanwhile, morning Lag_2 and daytime Lag_1 in the range of $\geq 2.00 \times 10^{-5}$ mW appeared to have a strong relationship with sleep loss (OR_{adj}1.60; 95% CI: 1.26–1.76, OR_{adj}1.36; 95% CI: 1.07–1.17). The relationship between Lag_4 daily dose and sleep loss took the form of a reverse dose-response.

Originality/value – Sleep loss in adolescents has an increasing trend of prevalence and has been found to be correlated with the highest SOP group ($\geq 2.00 \times 10^{-5}$ mW range). These results confirmed that increased and longer smartphone use result in reduced sleep time. This causes them to be exposed to smartphone electromagnetic radiation and smartphone screen lighting. This disturbs brain waves and nervous system controlling sleep balance mechanisms. The findings recommended parents setting time



© Wanna Chongchitpaisan, Phongtape Wiwatanadate, Assawin Narkpongphun, Surat Tanprawate and Nipapon Siripon. Published in *Journal of Health Research*. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at <http://creativecommons.org/licences/by/4.0/legalcode>

Journal of Health Research
Vol. 34 No. 4, 2020
pp. 317-327
Emerald Publishing Limited
2586-940X
DOI 10.1108/JHR-05-2019-0104

and boundaries around technology use at home to reduce contact with electromagnetic radiation and smartphone screen lighting, thereby increasing sleeping time in order to create good sleep quality.

Keywords Smartphone, Electromagnetic radiation, High school students, Sleep loss

Paper type Research paper

Introduction

Adolescents are sleeping less with recent mean sleeping times in a narrow range of 6.25–7.03 h (SD 1.39–1.04) per day[1, 2]. Sleep loss impacts both health and learning, especially among adolescents growing up in the era of mobile phones[3]. Adolescents experience growth and biological changes during the sleep-wake process controlled by the body's internal clock and hormone secretion for a balanced sleep. Because of increased nighttime activities, the circadian rhythm is delayed in adolescence who now enjoy spending increasingly late nights as “night owls” due to the use of modern technology[4]. The majority of systematic review findings indicated that the use of smartphones and their technological features before sleep cause the late onset of sleep and a reduction in the actual sleeping time[5]. Furthermore, increased technology usage has been correlated with sleep disturbances (odds ratio (OR) 1.79; 95% CI: 1.39–2.31) and reduced sleep time (OR 1.53; 95% CI: 1.11–2.10)[6, 7].

Smartphones are the latest type of mobile phone used for multiple purposes and used extensively by adolescents in Thailand[8]. Smartphones use electromagnetic wave transmission microwave frequencies sent from antennas to the destination's signal numbers via control channels at the base station. Assessment of the levels of contact with electromagnetic radiation and the amount of smartphone energy absorbed by human tissues was determined by the smartphone output levels[9]. Smartphones, when used very close to the head, can disrupt brain waves and wake-sleep cycles which in turn can have an effect on the secretion of neurotransmitters related to sleep and abnormalities in biological sleep[10]. When using smart phones at a close range, adolescents are exposed to smartphone electromagnetic radiation and smartphone screen lighting, which is a short-wavelength light (450 nm) that sends signals to the suprachiasmatic nuclei. Signals are then transmitted to the pineal gland to suppress the secretion of melatonin. Meanwhile, signals are transmitted from the visual photoreceptor system to stimulate the ascending arousal system in order to increase wakefulness. Additionally, signals are sent to suppress the ventrolateral preoptic nucleus system and the noradrenergic locus coeruleus in order to prevent sleep[11]. A previous study found that electromagnetic waves with frequencies similar to the brain wave frequencies increased responses in the brain[12]. This study investigated the correlation of smartphone output power (SOP) that reflects the smartphone electromagnetic radiation from smartphones causing sleep loss in high school students. Results will provide data for recommending safe mobile phone use and appropriate care and prevention for adolescents with sleep problems.

Materials and methods

Ethical considerations

The study was approved by the Ethics Committee for Human Research, Faculty of Medicine at Chiang Mai University (COM 2558-03316). Informed consent was obtained from all participants.

Study design and participants using questionnaire

The first phase of this cross-sectional study was conducted between October and December 2015 among 996 high school students in grades 10–12 in a Chiang Mai Provincial school who share common characteristics with other high school students in Thailand. The first phase of the study was conducted to identify the inclusion and exclusion criteria that required that the subjects were not obese (85th percentile, BMI in female 26.5–31.5, male 27–30.5), had no daily health-related behaviors including drinking liquor and smoking, had no sleep disorders and preexisting disease or health problems diagnosed by a doctor,

and were currently undergoing treatment. The exclusion criteria were both anxiety and depression scores equal to or more than 11 points, sleep hygiene scores of less than or equal to 20 points and severe illnesses or injuries. The second phase was a time-series study using the daily sleep questionnaire, conducted among 200 high school students who were selected from participants in the first phase based on an agreed set of criteria.

Data collection and sleep quality measurement

The students recorded data every day over a period of two to four months (60–120 days) in the daily questionnaires which were sent to the researchers via a smartphone application. The sleep daily questionnaires were applied by the seven components of the Pittsburg Sleep Quality Index (PSQI), which was translated into Thai with a Cronbach's α of 0.78[13]. The daily sleep questionnaires consisted of sleeping and waking times, frequency of times waking up at night, duration of sleep time for the entire night, sedative use, feelings after waking in the morning and after arriving at school, and sleep hygiene. The researcher collected and scored recorded daily sleep data to sleep latency, sleep duration, sleep efficiency, sleeping problems, sedative use, impacts of sleep problems on activities/education and sleepiness after waking. Then each domain of sleep quality was calculated into the PSQI scores. Prevalence of sleep-related problems were calculated from the number of students who had experienced sleep loss (< 8 h), sleep difficulty (> 20 min), inefficient sleep (< 85 percent) and poor sleep (PSQI score < 5) by the total number of observations from those who completed a sleep diary. Furthermore, headache onset was assessed by using a headache diary consisting of the time when the headache began and stopped, and the characteristics of the headache. Anxiety and depression were assessed by the Hospital Anxiety and Depression form in the first phase and were scored by daily questionnaires. Smartphone use was recorded in the daily questionnaire by recording telephone conversations over the internet and hand-free or speakerphone use.

The SOP measurement

Smartphone electromagnetic radiation was measured by SOP from the smartphone antenna. The application was developed to collect SOP on Android and IOS operating systems. The application requested access to the SOP via the program's framework by setting it to save every 5 min and transmitting saved data by e-mail to a researcher. The mean power output of the smartphone was collected from the measurements taken at 5-min intervals for 15 min. The daily dosage data were calculated as the sum of the average output power multiplied by the duration time whilst measuring the SOP. SOP was collected at four different time periods: 12:01 a.m.–6:00 a.m., 6:01 a.m.–12:00 p.m., 12:01 p.m.–6:00 p.m. and 6:01 p.m.–12:00 a.m. The SOP was continuous data with a non-normal distribution and divided into three groups. The study measured the error of output power from smartphones by spectrum analyzers which are the gold standard on analyzing tools. Because different brands of smartphones have different power outputs, the same error figure was used to adjust the output power for normalization into the same brands of smartphones.

Statistical analysis

The sample size was calculated based on a 10 percent prevalence of headaches thought to be caused by mobile phone use[14] in the first phase. The 200 high school students were selected by inclusion criteria into the second phase. The students filled out the daily questionnaire ranging from 60 days to 120 days in order to account for any missing records. A total of 145 students completed data comprising of 12,969 records which were coded and analyzed using a Statistical Package for Social Science software version 20 to obtain frequency, arithmetic mean and standard deviation. Relationships between SOP and sleep loss, sleep efficiency, poor sleep, OR and their 95% confidence intervals (95% CI) with p -value < 0.05 was considered statistically significant, were estimated using generalized

estimating equations (GEE). The analysis was also performed to control the confounding effects of factors such as gender, age, poor sleep hygiene, coffee drinking, headache, anxiety, depression, internet use, hand-free device use and smartphone use which might distort the research outcomes. The GEE was used for the data in the same cluster such as time-series data which is a series of data set on a single member of a unit of observation (each student in this study) or a cluster, and was analyzed for the time lag. The data on SOP were aggregated over four time periods with the SOP use in the evening and nocturnally was pre-bedtime and during sleep time use. Using smartphones during the daytime and mornings were lag_1 and lag_2 at 6-h lags (or delayed effect) and daily lags (24 h).

Therefore, in the analysis, the correlational structure was set and considered by the low score of Quasi-Likelihood under Independence Model Criterion. The Corrected Quasi-likelihood under Independence Model Criterion (QICC) has been used to compare the models under one correlational structure. A lower QICC score corresponded to a model that was a better fit.

Results

The majority of the students in the batch were female, averaging 17.4 years old and of normal health, which was also a criterion for the selection of participants. The study found that most participating high school students went to bed late and woke up late (Table I). The prevalence of sleep loss (< 8 h) was found to be 52.9 percent and the average sleep duration was 7.4 ± 1.7 h, while the findings in the first phase showed 55.4 percent of students slept after 10:00 p.m., causing sleep loss with a mean sleeping time of only 6.88 ± 1.28 h. The prevalence of sleep latency was only 8.2 percent, inefficient sleep 8.5 percent and poor sleep 32.1 percent. The mean sleep quality score was 3.7 ± 2.07 and that was lower than the study in phase 1 with a mean score at 4.8 ± 2.9. Meanwhile, the results showed a prevalence

Variables	<i>n</i>	Minimum	Maximum	Mean ± SD
Time to bed	12,696	5.00 p.m.	8.13 p.m.	24.26 ± 2.0
Time wake up	12,696	1.00 a.m.	23.35 p.m.	8.04 ± 2.27
PSQI score	12,696	0	12	3.7 ± 2.1
Duration of sleep time	12,696	0.30 h	16 h	7.4 ± 1.7
Sleep efficiency	12,696	22.9%	100%	95.4 ± 7.1
Variables				<i>n</i> (%)
<i>Sleep loss (h)</i>				
< 8				6,717 (52.9)
≥ 8				5,979 (47.1)
<i>Daytime sleepiness</i>				
Yes				9,313 (73.4)
No				3,383 (26.6)
<i>Bad hygiene sleep</i>				
Yes				6,613 (52.1)
No				6,083 (47.9)
<i>Coffee or tea drink during the day</i>				
No				6,547 (51.6)
1-5				6,137 (48.3)
> 5				12 (0.1)
Table I.				
Characteristic sleep of participants presented as percentage	<i>MP USE @NIGHT</i>			
	Yes			3,542 (27.9)
	No			9,154 (72.1)

of daytime sleepiness at 73.4 percent; 48.4 percent drank coffee and 27.9 percent used a smartphone before going to bed.

The data on SOP was adjusted considering the value of error measured from each device brand to normalize the value for all device brands. In the present study, SOP use in the daytime and morning was lag_1 and lag_2 at 6-h lags (or delayed effect) and daily lags (24 h).

The SOP observations were then divided into three ranged groups: less than 1.79, 1.8–1.99 and more than 2.0×10^{-5} mW (Table II). The most common range of SOP to which the samples were exposed was found at more than 2.0×10^{-5} mW, 80.6 percent of the observations, during all periods of the day but primarily during the evening. SOP in the range of 1.8–1.99 $\times 10^{-5}$ mW appeared the least prevalent, only 2.4 percent of the observations, taking place mostly during the nocturnal hours. SOP in the range of $< 1.79 \times 10^{-5}$ mW, 31.4 percent of the observations, corresponded to smartphone use in the morning.

To control the confounding effects, we conducted a statistical test to evaluate the relationship between various factors and found no interaction effect among them. Additional computation was made to adjust the effects of such potential confounders as demographic characteristics, and characteristics of smartphone use.

The results found anxiety, depression and headache have relationships with sleep loss OR_{adj}1.06; 95% CI: 1.02–1.11, OR_{adj}1.04; 95% CI: 1.00–1.08 and OR_{adj}1.16; 95% CI: 1.03–1.31, (Table III). Younger age and abnormal BMI rates were more strongly related to poor sleep OR_{adj}1.15; 95% CI: 1.00–1.32 and OR_{adj}2.12; 95% CI: 1.38–3.23. The daily dose, evening and nocturnal SOP in the range of $\geq 2.00 \times 10^{-5}$ mW had 1.32, 1.34 and 1.41 times (95% CI: 1.08–1.60, 95% CI: 1.02–1.77 and 95% CI: 1.09–1.82), respectively, stronger relationship with sleep loss than their effects in the range of $\leq 1.79 \times 10^{-5}$ mW. Meanwhile, morning lag_2 and daytime lag_1 in the range of $\geq 2.00 \times 10^{-5}$ mW were found to have 1.60 and 1.36 times (95% CI: 1.11–2.31 and 95% CI: 1.04–1.77), respectively, stronger relationship with sleep loss compared to their effects in the other two ranges. The relationship between lag_4 daily dose and sleep loss was found to be in the form of a reverse dose-response. The result revealed that sleep loss responded to SOP in the range of $\geq 2.00 \times 10^{-5}$ mW, meaning that more SOP or more smartphones use reduced sleep time.

Meanwhile, the daily dose SOP in the range of $\leq 1.79 \times 10^{-5}$ mW and the $\geq 2.00 \times 10^{-5}$ mW had 4.54 and 3.81 times (95% CI: 3.33–6.20 and 95% CI: 2.59–5.60), respectively, stronger relationship with inefficient sleep than their effects in the range of 1.80–1.99 $\times 10^{-5}$ mW (Table IV). Finally, the daily dose and morning lag_2 SOP in the range of $\geq 2.00 \times 10^{-5}$ mW had 1.30 and 1.48 times (95% CI: 1.03–1.64 and 95% CI: 1.05–2.11), respectively, stronger relationship with poor sleep. Furthermore, nocturnal and daytime lag_1 SOP in the 1.80–1.99 $\times 10^{-5}$ mW range also had 1.66 and 1.48 times (95% CI: 1.15–2.40 and 95% CI: 1.01–2.17), respectively, stronger relationship with poor sleep. The results showed inefficient sleep and poor sleep responded to SOP in two ranges.

Apparently, the daily dose SOP in the range of $\leq 1.79 \times 10^{-5}$ mW and $\geq 2.00 \times 10^{-5}$ mW had 4.54 and 3.81 times (95% CI: 3.33–6.20 and 95% CI: 2.59–5.60), respectively, stronger relationship with inefficient sleep than their effects in the range of 1.80–1.99 $\times 10^{-5}$ mW (Table IV).

Output power ($\times 10^{-5}$ mW)	Daily dose <i>n</i> (%)	Morning <i>n</i> (%)	Daytime <i>n</i> (%)	Evening <i>n</i> (%)	Nocturnal <i>n</i> (%)
≤ 1.79	1,943 (15.3)	3,597 (31.4)	2,479 (20.1)	2,303 (18.8)	2,648 (20.9)
1.8–1.99	186 (1.5)	226 (2.0)	120 (1.0)	79 (0.6)	301 (2.4)
≥ 2.0	10,567 (83.2)	7,646 (66.7)	9,710 (78.9)	9,896 (80.6)	9,747 (76.8)

Table II.
Smartphone output power group by cycle time and daily dose

Table III.
Odds ratios (OR) of sleep loss and their 95% confidence intervals for each factor and daily dose adjusted for all other factors using GEE (Exchangeable, QIC = 15,141.01, QICC = 15,054.85)

Factor	Sleep loss < 8 h		Crude OR	Adjusted OR	95% CI		p-value
	Yes	No			Lower	Upper	
Anxiety score mean ±SD	2.1 ± 2.6	1.5 ± 2.2	1.05	1.06	1.02	1.11	< 0.01
Depression score mean ±SD	1.7 ± 2.4	1.2 ± 2.0	1.08	1.04	1.00	1.08	0.04
Lag_4 dose (× 10 ⁻³ mW) mean ±SD	1.7 ± 7.0 6,717	2.4 ± 22.0 5,979	0.003	0.003	1.16 × 10 ⁻⁵	0.89	0.05
Factor	Total	Sleep loss %	Crude OR	Adjusted OR	Lower	Upper	p-value
Headache: yes/no	1,705/10,991	57.0/52.3	1.21	1.16	1.03	1.31	0.02
Daily dose group (×10 ⁻⁵ mW)							
≥2.00/≤1.79	10,567/1,943	53.8/48.5	1.30	1.32	1.08	1.60	< 0.01
Evening dose group (×10 ⁻⁵ mW)							
≥2.00/≤1.79	9,747/2,648	53.8/50.2	1.13	1.34	1.02	1.77	0.04
Nocturnal dose (×10 ⁻⁵ mW)							
≥2.00/≤1.79	7,646/3,597	55.6/47.7	1.27	1.41	1.09	1.82	< 0.01
Morning dose group (×10 ⁻⁵ mW)							
≥2.00/180-199	9,710/120	54.9/41.7	1.44	1.60	1.11	2.31	0.01
Daytime dose group (×10 ⁻⁵ mW)							
≥2.00/≤1.79	9,896/2,303	54.5/47.7	1.32	1.36	1.04	1.77	0.03

Note: Adjust by age, BMI, vision, anxiety, depression, bad hygiene sleep, coffee drink, headache, internet use, hand-free use, brand device, smartphone output power

Finally, the daily dose and morning lag₂ SOP in the range of $\geq 2.00 \times 10^{-5}$ mW had 1.30 and 1.48 times (95% CI: 1.03–1.64 and 95% CI: 1.05–2.11), respectively, stronger relationship with poor sleep. Meanwhile, nocturnal and daytime lag₁ SOP in the range of $1.80\text{--}1.99 \times 10^{-5}$ mW also had 1.66 and 1.48 times (95% CI: 1.15–2.40 and 95% CI: 1.01–2.17), respectively, stronger relationship with poor sleep. The results showed inefficient sleep and poor sleep responded to SOP in two ranges.

Discussion

In the present study, the mean sleep time was 7.4 ± 1.7 h with a prevalence of sleep loss (< 8 h) at 52.9 percent, whereas the mean sleep time was $6.25 \pm 1.39\text{--}7.03 \pm 1.04$ h in a previous study[1, 2]. A study involving the effect of technology use at night on sleep loss showed mean sleep duration was also on a decreasing trend. Smartphone use before sleep in this study was 27.9 percent and concurred with the findings from a previous study where mobile phone use before sleep was at 23.6–62 percent[7, 15]. In addition, the findings concur with the study on the factors related to sleep quality in Stage 1, which found smartphone use before sleep to influence sleep loss (OR_{adj}1.82: 95% CI, 1.10–3.01). Furthermore, smartphone use before sleep frequently involves conversations for entertainment and social media use, meaning that students tend to use smartphones for a long time, and this causes students to sleep later. The result in the first phase showed 55.4 percent of students slept after 10:00 p.m., causing sleep loss with a sleeping time of only 6.88 ± 1.28 h. Thus, smartphone usage at night was found to pose a risk for sleepiness in the morning after waking up (OR_{adj}1.70: 95% CI, 1.08–2.66). The recent study revealed that the students reported waking during the night to answer text messages was at 47 percent and answering phone calls were at 40 percent[1]. The consequence of daytime sleepiness in this study was found as high as 73.4 percent, which concurs with the findings of other studies at 70–90.4 percent[16]. The present result on coffee drinking was at 48.4 percent, indicating that students who were deprived of sleep drank coffee to help keep them awake.

Evidently, anxiety, and depression created risks for sleep loss (OR_{adj}1.04–1.06; 95% CI: 1.02–1.1). Previous studies have found anxiety and depression to be common co-morbidities encountered with sleep problems in adolescents[17]. A study by Augner found the quality of sleep to be correlated with depression $r = -0.57$ and anxiety $r = -0.54$ ($p < 0.01$)[18]. Meanwhile, adolescents experience physical changes resulting from growth that leads to susceptibility to depression. The thalamocortical circuit is triggered in addition to the serotonergic, noradrenergic, cholinergic and GABAergic systems. As a result, the sleep regulation system and electrical brain waves are disrupted through the suppression of the sleep spindle before the occurrence of depression[18].

Headaches correlated with sleep loss (OR_{adj}1.2; 95% CI: 1.03–1.3) have been found to disrupt sleep. Although sleep has been found to help relieve headaches, sleep problems can

Table IV.

Odds ratio (OR) of inefficient sleep and their 95% confidence intervals for each factor and the daily dose adjusted for all other factors using GEE (exchange, QIC = 6,297.93, QICC = 6,275.83)

Factor	Total	Inefficient sleep (< 85%)	Crude OR	Adjusted OR	95% CI		<i>p</i> -value
					Lower	Upper	
<i>Daily dose group</i> ($\times 10^{-5}$ mW)							
$\leq 1.79/1.80\text{--}1.99$	1,943/186	11.8/3.8	4.51	4.54	3.33	6.20	< 0.01
$\geq 2.00/1.80\text{--}1.99$	10,567/186	8.0/3.8	3.79	3.81	2.59	5.60	< 0.01

Note: Adjust by age, BMI, vision, anxiety, depression, bad hygiene sleep, coffee drink, headache, internet use, hands-free use, brand device, SOP

also trigger headaches[19]. In terms of process, the hypothalamus, which is connected to the limbic system, retinohypothalamic tract and brain-stem aminergic nuclei are triggered and cause migraines. Concurrently, the hypothalamus is connected to the periaqueductal gray (PAG) matter. It triggers orexin to result in “rapid-eye-movement sleep-off,” while orexin triggers the ventrolateral part of the PAG matter, which suppresses antinociceptive activity in the trigeminal nucleus caudalis and leads to migraines[20].

Sleep loss was found to respond to SOP in the highest volume range ($\geq 2.0 \times 10^{-5}$ mW). The majority of systematic review findings indicated that the use of smartphones and new technology before sleep causes a later sleep time. Adolescent use of smartphones in the evening and at night after lights out at 9:00 p.m. increased by 62–72 percent in the group findings[5]. Furthermore, smartphone and internet use from midnight to 3:00 a.m. was found to be as high as 34–55 percent[5] and consisted of texting messages, chatting and online activities with 24 percent consisting of video games. These were correlated with sleep disturbance and reduced sleep time and quality[21, 22]. In the present study, the mean sleep time was 7.4 ± 1.7 h with the presence of sleep loss (< 8 h) at 52.9 percent. Similarly, sleep loss (< 7 h) in an American study was at 61 percent[23]. Furthermore, the study findings in Stage 1 found the prevalence of sleep loss to be 67.7 percent with a mean sleep time of 6.9 ± 1.3 h. The data indicate a decreasing trend of mean sleep time. The heavy smartphone usage in the morning from 6:00 a.m. to 12:00 p.m. resulted in delayed effects on sleep loss. This result has confirmed that increased and longer SOP use can result in reduced sleep time.

The daily dose SOP has delayed effects (24 h) on sleep loss (lag 4) in the form of reverse dose-response. The findings of the present study are consistent with the study by Lowden *et al.*[24] in which an experiment was conducted to administer repeated microwave frequency radiation exposures for periods of 4 h. The study found increased brain wave activity at 30 min, 1 h and 2 h of sleep in Stage 2, while no changes were found on the electrical brain waves during the third hour of sleep in Stage 2. This shows that prolonged electromagnetic radiation exposure has acute and continuous impacts[24]. In addition, a study of lab rats exposed to smartphone electromagnetic radiation through GSM signals from smartphones for 2 h found different levels of albumin leaking out from the arteries of the rats at 2 h, 7 days and 14 days after recovery at 50, 25 and 29 percent, respectively[25]. The increased leak in albumin at 14 days took place as a U-curve response or delayed effects of a daily dose of SOP on sleep loss in the form of reverse-dose response.

The mechanism of SOP disturbs the cortical neurons, causing the reticular nucleus of the thalamus in the subcortical region to send signals to the cortex, leading to changes in electrical brain waves. As a result, the brain wave power in the α frequency band and sleep spindle in the non-REM sleep stage increases[26], while slow-wave sleep decreases [24]. Furthermore, adolescents use smartphones for a long time frequently at night which causes them to be exposed to smartphone screen lighting, which is short-wavelength light (450 nm) that sends signals to the suprachiasmatic nuclei. Signals are then transmitted to the pineal gland to suppress the secretion of melatonin. Meanwhile, signals are transmitted from the visual photoreceptor system to stimulate the ascending arousal system in order to increase wakefulness. Signals are also sent to suppress the ventrolateral preoptic nucleus system and the noradrenergic locus coeruleus in order to prevent sleep[11, 27]. According to the findings, the secretion of melatonin from the pineal gland was sensitive to electromagnetic waves[28]. This causes the telephone users to sleep later, causing sleep loss.

Smartphones were developed to meet the many different needs of adolescents. But smartphones have also become a neo pollutant potentially interfering with both sleep quality and quantity, particularly when smartphones become more responsive to diverse

needs and are more widely available to adolescents. The study findings show that SOP creates risks for sleep difficulty and morning sleepiness (≤ 1.79 and $1.80\text{--}1.99 \times 10^{-5}$ mW). Meanwhile, inefficient sleep is a calculation of the total sleep time and duration in bed. Therefore, there are responses to SOP in two ranges (≤ 1.79 and $\geq 2.0 \times 10^{-5}$ mW). The information provided has indicated that SOP influences the parts of the nervous system that are responsible for sleep regulation.

The study had limitations because the smartphone's output power was measured using the data in the smartphone, not measuring the electromagnetic radiation from outside the phones. As a result, our smartphone users in the test group were not shown with all the possible forms of radiation exposure. However, in reality, the participants are always exposed to outside electromagnetic radiation which could lead to a misclassification of exposure. This study was a panel study, meaning the outcomes and exposures were followed in the same sample group. The same samples have the same underlying confounding factors, and this can be considered as controlling individual and environmental confounders. The method of collecting data used in this study relied on the technology by creating an application that was used to answer questions. Every parameter of sleep was collected so the information was as accurate as possible and there was no recall bias from the participants.

Conclusion

Adolescents use smartphones for long periods of time and frequently at night. This causes them to be exposed to smartphone electromagnetic radiation and smartphone screen lighting. This, in turn, disturbs brain waves and the nervous system controlling sleep balance mechanisms and wake-sleep cycles related to sleep and abnormalities in biological sleep. Sleep loss in adolescents is an increasing trend and sleep loss has been found to be correlated with the highest SOP group ($\geq 2.00 \times 10^{-5}$ mW range). These results confirmed that increased and longer smartphone use results in reduced sleep time. The findings recommend that parents set time boundaries around technology use at home. This will help to reduce contact with electromagnetic radiation and smartphone screen lighting thereby hopefully increasing sleep time in order to create a better sleep quality.

Acknowledgments

Financial disclosure: the authors have indicated they have no financial relationships relevant to this paper to disclose.

The authors gratefully acknowledge the Faculty of Medicine, Chiang Mai University for financial support for this study and the teachers and students in Wattanothai Payap School for their engagement and help with the data collection in the study.

Conflict of interest: the authors have no conflicts of interest relevant to this paper to disclose.

References

1. Adams SK, Kisler TS. Sleep quality as a mediator between technology-related sleep quality, depression, and anxiety. *Cyberpsychol Behav Soc Netw*. 2013 Jan; 16(1): 25-30
2. Hysing M, Pallesen S, Stormark KM, Lundervold AJ, Sivertsen B. Sleep patterns and insomnia among adolescents: a population-based study. *J Sleep Res*. 2013 Oct; 22(5): 549-56
3. Prensky M. *Digital natives, digital immigrants*. MBC University Press. 2001 Sept; 9(5): 1-5.
4. Hershner SD, Chervin RD. Causes and consequences of sleepiness among college students. *Nat Sci Sleep*. 2014 Jun; 6: 73-84.

5. van den Bulck J. Television viewing, computer game playing, and internet use and self-reported time to bed and time out of bed in secondary-school children. *Sleep*. 2004 Feb; 27(1): 101-104.
6. Carter B, Rees P, Hale L, Bhattacharjee D, Paradkar MS. Association between portable screen-based media device access or use and sleep outcomes a systematic review and meta-analysis. *JAMA Pediatr*. 2016 Dec 1; 170(12): 1202-208.
7. Owens J. Insufficient sleep in adolescents and young adults: an update on causes and consequences. *Pediatrics*. 2014 Sep; 134(3): 921-32.
8. Electronic Transectors Development Agency. Thailand internet user profile 2013. 2013 Available from: www.slideshare.net/noumfone/presentation-internetuserprofile-25098101
9. Vrijheid M, Mann S, Vecchia P, Wiart J, Taki M, Ardoino L, *et al*. Determinants of mobile phone output power in a multinational study: implications for exposure assessment. *Occup Environ Med*. 2009 Oct; 66(10): 664-71.
10. Arora T, Broglia E, Thomas GN. Associations between specific technologies and adolescent sleep quantity, sleep quality, and parasomnias. *Sleep Med*. 2014 Feb; 15(2): 240-7.
11. Cajochen C. Alerting effects of light. *Sleep Med Rev*. 2007 Dec; 11(6): 453-64.
12. Mohammed HS, Fahmy HM, Radwan NM, Elsayed AA. Non-thermal continuous and modulated electromagnetic radiation fields effects on sleep EEG of rats. *J Adv Res*. 2013 March; 4(2): 181-7.
13. Chanamanee P, Taboonpong S, Intanon T. Sleep quality and related factors among university students in Southern Thailand. *Songkla Med J*. 2006 April; 24(3): 163-73.
14. Chu MK, Song HG, Kim C, Lee BC. Clinical features of headache associated with mobile phone use: a cross-sectional study in university students. *BMC Neurol*. 2011 Sep 26; 11(115): 1-7.
15. Bruni O, Sette S, Fontanesi L, Baiocco R, Laghi F, Baumgartner E. Technology use and sleep quality in preadolescence and adolescence. *J Clin Sleep Med*. 2015; 11(12): 1433-41.
16. Guo L, Deng J, He Y, Deng X, Huang J, Huang G, *et al*. Prevalence and correlates of sleep disturbance and depressive symptoms among Chinese adolescents: a cross-sectional survey study. *BMJ Open*. 2014 Jul 29; 4(7): 1-9.
17. Junker A, Bjørngaard JH, Gunnell D, Bjerkeset O. Sleep problems and hospitalization for self-harm: a 15-year follow-up of 9,000 Norwegian adolescents: the Young-HUNT study. *Sleep*. 2014 March; 37(3): 579-85
18. Augner C. Associations of subjective sleep quality with depression score, anxiety, physical symptoms and sleep onset latency in students. *Cent Eur J Public Health* 2011 March; 19(2): 115-17.
19. Bellini B, Arruda M, Cescut A, Saulle C, Persico A, Carotenuto M, *et al*. Headache and comorbidity in children and adolescents. *J Headache Pain*. 2013 Sep; 14(79): 1-11.
20. Dosi C, Riccioni A, Della Corte M, Novelli L, Ferri R, Bruni O. Comorbidities of sleep disorders in childhood and adolescent: focus on migraine. *Nat Sci Sleep*. 2013 Jun 11; 5: 77-85.
21. Neralie C, Gradisar M. Electronic media use and sleep in school-aged children and adolescents: a review. *Sleep Med*. 2010; 11(8): 735-42.
22. Arora T, Hussain S, Hubert Lam KB, Lily Yao G, Neil Thomas G, Taheri S. Exploring the complex pathways among specific types of technology, self-reported sleep duration and body mass index in UK adolescents. *Int J Obes*. 2013 Jan; 37: 1254-1260.
23. National Sleep Foundation. Sleep in America poll: communication technology in bedroom; 2011. [cited 2019 May]. Available from: www.sleepfoundation.org/sites/default/files/sleepinamericapoll/SIAP_2011_Summary_of_Findings.pdf
24. Lowden A, Akerstedt T, Ingre M, Wiholm C, Hillert L, Kuster N, *et al*. Sleep after mobile phone exposure in subjects with mobile phone-related symptoms. *Bioelectromagnetics*. 2011 Jan; 32(1): 4-14.
25. Nittby H, Brun A, Eberhardt J, Malmgren L, Persson BR, Salford LG. Increased blood-brain barrier permeability in mammalian brain 7 days after exposure to the radiation from a GSM-900 mobile phone. *Pathophysiology*. 2009 Aug; 16(2-3): 103-12.

-
26. Huber R, Schuderer J, Graf T, Jütz K, Borbély AA, Kuster N, *et al*. Radio frequency electromagnetic field exposure in humans: estimation of SAR distribution in the brain, effects on sleep and heart rate. *Bioelectromagnetics*. 2003 May; 24(4): 262-76.
 27. Hale L, Guan S. Screen time and sleep among school-aged children and adolescents: a systematic literature review. *Sleep Med Rev*. 2015 Jun; 21: 50-8.
 28. Lewczuk B, Redlarski G, Zak A, Ziolkowska N, Przybylska-Gornowicz B, Krawczuk M. Influence of electric, magnetic, and electromagnetic fields on the circadian system: current stage of knowledge. *Biomed Res Int*. 2014 July; 2014: 1-13.

Corresponding author

Phongtape Wiwatanadate can be contacted at: pwiwatanadate@gmail.com

For instructions on how to order reprints of this article, please visit our website:

www.emeraldgrouppublishing.com/licensing/reprints.htm

Or contact us for further details: permissions@emeraldinsight.com