Original Article

Effect of Smartphone Output Power on the Undetermined Headache among High School Students: Time-Series Study

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Background: The undetermined headache, which is not classified as a primary headache, might be a mobile phone associated headache (MPAH).

Objective: To investigate the smartphone electromagnetic radiation related to undetermined headaches among high school students.

Materials and Methods: One hundred forty-five high school students in the Chiang Mai Province completed a headache diary according to the International Classification of Headache Disorders version 3 beta criteria. It was scored according to the diagnosis algorithm. The smartphone output power (SOP) as measured and recorded by the smartphone application was saved every five minutes and transmitted by email. The completed data included 12,969 entries. The smartphone use, sleep quality, anxiety, and depression were also assessed. Data were analyzed using the Generalized Estimating Equation adjusted for demographic data, smartphone use, and sleep quality, and other.

Results: Most students were female 74.7% with a mean age of 17.63±1.01 years (range 16 to 20). The one-year headache prevalence was 92.6% (95% CI 90.8 to 94.1) with undetermined headaches at 18.7% and 16.9% in the first and second phase, respectively. Characteristically, the prevalence of MPAH was higher in the nature of short duration pain, pulsing and tightening, indefinite form of pain, pain occurring in the morning, one side headache at occipital or frontal areas, and low pain severity ($p<0.05$). The results revealed the strongest effect of SOP at 1.80×10^{-5} to 1.99×10^{-5} mW range on the undetermined headaches with OR_{adj} 2.32; 95% CI 1.23 to 4.34. Furthermore, the undetermined headaches also had the strongest association with hand-free use and internet use (OR_{adj} 1.92; 95% CI 1.11 to 3.29 and OR_{adj} 2.33; 95% CI 1.71 to 3.19, respectively), age, and anxiety (OR_{adj} 1.49; 95% CI 1.26 to 1.76 and OR_{adj} 1.12; 95% CI 1.07 to 1.17, respectively).

Conclusion: The undetermined headache associated with SOP, which was a MPAH. These results suggest that an older age for starting smartphone use and utilizing a hand-free device were recommended to prevent chronic headaches.

Keywords: Smartphone output power, Undetermined headache, Mobile phone associated headache

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The undetermined headache has specific characteristics that are not classified as a primary headache. A previous study had shown that increasing headache prevalence in teenagers affected their learning ability and quality of student life as well as caused a burden to their parents in terms of treatment costs(1,2). Teenagers are growing up in a digital age and are ranking in the top three of the highest possession and use of smartphones(3). Smartphone or mobile phone (MP) work within a range of frequency between 900 and 2,100 MHz. Its electromagnetic radiation sends the signal from the antenna of the smartphone to a base station and mobile telecommunications

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switching office to connect the communication[4]. The electromagnetic energy is absorbed into the head or other organs of the smartphone user. Thus, smartphone use is the source of electromagnetic radiation closest to the head[5,6], which will lead to chemical and biological changes in cells[5] with the neurological signs and behavior from the change in the nervous system[6].

Previous studies on health effects from MP use generally reported findings related to headaches (16.1% to 65%)[7,8]. Electromagnetic radiation from smartphones was found to affect the areas of the thalamus, raphe magnus nucleus, and spinal cord and decrease the neurotransmitters such as acetylcholine, neuronal nAChR, and dopamine-opiate system. These have an important role in inhibiting pain[9,10]. The global concerns about MP use and health effects, especially in children and teenagers, prompted the World Health Organization (WHO) to commission a research to assess the health risks from using MPs in children and teenage groups[11]. A previous study showed that MP associated headache (MPAH) had specific characteristic that might be classified as undetermined headache[12].

However, the effect of MP use on headaches remained unclear. The present study investigated the relationship between the electromagnetic radiation from MP and headaches especially undetermined headaches and MPAH and will provide data for recommending safe smartphone use as well as appropriate care and prevention for adolescents with headaches.

Materials and Methods

The cross-sectional study in the first phase was conducted on high school students in a Chiang Mai Provincial school who shared common characteristics with other students at a high school level in Thailand between October and December 2015 using a questionnaire. The sample size was calculated from the prevalence of headace attack by MP use in Korea at 10%[12]. The samples of 1,058, composed of grade 10 to 12 high school students, were identified by stratified random sampling method in which the numbers of samples were proportional to population size in each gender and grade stratum. The questionnaire response rate was 94.1% (996 students). The questionnaire was adapted from the Headache-Attributed Restriction, Disability, Social Handicap, and Impaired Participation questionnaire, which was developed for children and teenagers[13,14]. The headache was diagnosed based on the International Classification Headache Disorder version 3 beta criteria and classified by scoring according to a diagnosis algorithm. Migraine will be grouped first then followed by tension type headache (TTH), and undetermined headache. The researchers assessed the anxiety and depression using the Hospital Anxiety and Depression questionnaire in the Thai language version[15]. The sleep quality was assessed using the Pittsburg Sleep Quality Index (PSQI). Finally, the questionnaire on the part of characteristics of MP use was adapted from the study of Chu et al[12]. The MPAH was defined as headache attack during or after MP use within two hours. The second phase was the time series study using the daily activity questionnaire. A sample of 145 students, composed of grade 10 to 12 high school students, were selected from the first phase based on a set of criteria. The inclusion criteria were subjects have owned at least one smartphone, not obese, and had no diseases or other health problems diagnosed by doctors and undergoing treatment. Sleep quality, anxiety, depression, and smartphone use were also assessed. The data were regularly recorded every day over a period of two to four months (60 to 120 days) by a smartphone application. The smartphone output power (SOP) in the present study reflected the smartphone electromagnetic radiation that was measured and recorded by the application and set to save every five minutes and to send data by email to a researcher every day. The SOP was continuous data and divided to three groups. The study was approved by the Ethics Committee for Human Research, Faculty of Medicine at Chiang Mai University.

Statistical analysis

The questionnaire response rate in the first phase was 94.1%. The prevalence was expressed in percentage with 95% confidence interval (CI) and comparison of differences between groups was made using chi-square test with p-value of less than 0.05 as a statistically significant level. The completed data in second phase produced 12,969 entries, which were coded and analyzed using the IBM SPSS Statistics software, version 20 (IBM Corp., Armonk, NY, USA) to obtain frequency, arithmetic mean with standard deviation, and chi-square. Relationships between SOP and undetermined headaches, odds ratio (OR) and their 95% CIs were investigated with p-value of less than 0.05 considered statistically significant. The Generalized Estimating Equations (GEE) was also performed to control the confounding effects of such factors as demographic data, coffee or tea drinking, anxiety, depression, smartphone use, and

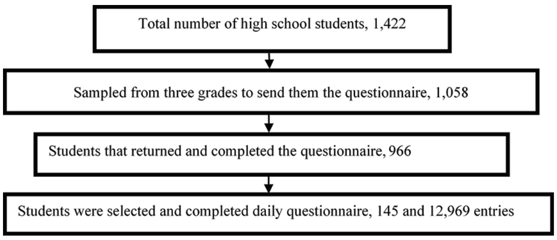

Figure 1. The Sampling procedure and sample response flow chart.

sleep quality. The GEE is appropriate for correlated data in the same cluster of dependent variables. In the analysis, the correlational structure was set and considered the low score of quasi-likelihood under independence model criterion (QIC). The corrected QIC (QICC) had been used to compare the models under one correlational structure. Low QICC scores indicated that a model was a fit.

Results

Out of the 1,422 high school student population, 1,058 students were randomly selected, and 996 (94.1%) responded to the survey for the analyses. One hundred forty-five high school students were selected in second phase and completed data that produced 12,969 entries (Figure 1).

Demographic characteristics

Most students were female 74.7% (744) with a mean age of 17.4±1.01 years old (range 16 to 20) and with normal health condition.

Prevalence of headaches and characteristics of MPAH

The one-year prevalence of headaches was 92.6% (Table 1). When excluding co-morbidity diseases of headaches, the highest prevalence was TTH and probable TTH with 22.4% and 46.2%, respectively. The prevalence of MPAH was 77.7%. In the second phase, the highest prevalence of headache was of a TTH, 74.1%, followed by undetermined and migraine types at 16.9% and 9.0%, respectively (Table 1, 2). The authors found that higher MPAH prevalence statistically significantly occurred among students with short time pain, pulsing and tightening, unstable increase or decrease of pain, and undetermined form of pain, pain mostly in the morning, with headache on one side and pain at the occipital and frontal areas (Table 3). The higher MPAH prevalence also occurred with statistical significance among students with lower severity of pain scores.

Table 1. Prevalence of headache and detail of headache and their 95% CIs unless specified otherwise (first phase)

Headache	n (%)	95% CI	
		Lower	Upper
Headache	922 (92.6)	90.8	94.1
Migraine + probable migraine	112 (12.2)	9.6	15.3
TTH + probable TTH	622 (67.4)	61.6	73.5
Undetermined headache	172 (18.7)	16.2	21.3
Headache with underlying	16 (1.7)	1.0	2.8
MP headache associated	716 (77.7)	74.8	80.3
<10 times/year	288 (40.2)	36.6	43.9
≥10 times/year	428 (59.8)	56.1	63.4
Score pain; mean±SD	3.44±1.885		

CI=confidence interval; TTH=tension type headache; MP=mobile phone; SD=standard deviation

Table 2. Headache type of participants presented as percentage (second phase)

Variable	n (%)
Headache	
Yes	1,705 (13.4)
No	10,991 (86.6)
Total	12,696 (100)
Headache type	
Migraine	153 (9.0)
TTH	1,264 (74.1)
Undetermined	288 (16.9)
Total	1,705 (100)

TTH=tension type headache

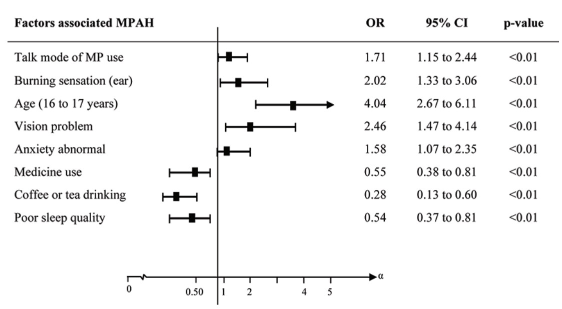

Figure 2. Factors contributing to MPAH presented as odds ratio adjusted for gender, BMI, underlying disease, head and neck injury, PTIEs, phobia, trigger, anxiety and depression, using multiple logistic regression.

Factors causing MPAH

The adjusted OR indicated that the students regularly using MP in talking mode were 1.7 times

Table 3. Prevalence of mobile phone associated headache use by characteristics of headache

Characteristic of headache	Total	MPAH <10 times/year n (%)	MPAH ≥10 times/year n (%)	Total MPAH n (%)	p-value
Frequency pain/year					0.26
<5 times/month	796	243 (30.5)	378 (47.5)	621 (78.0)	
≥5 times/month	115	45 (39.1)	50 (43.5)	95 (82.6)	
Duration pain					<0.01
Short time (second)	478	149 (31.2)	252 (52.7)	401 (83.9)	
5 minutes to 4 hours	394	126 (32.0)	158 (40.1)	284 (72.1)	
>4 hours	39	13 (33.3)	18 (46.2)	31 (79.5)	
Characteristic of pain					0.03
Pulsing	515	151 (29.3)	262 (50.9)	413 (80.2)	
Tightening	166	62 (37.3)	74 (44.6)	136 (81.9)	
Dull and other	230	75 (32.6)	92 (40.0)	167 (72.6)	
Model of pain					<0.01
Short period	207	45 (21.7)	55 (26.6)	100 (48.3)	
Instable pain	377	142 (37.7)	171 (45.3)	313 (83.1)	
Continuous pain	129	59 (45.7)	49 (38.0)	108 (83.7)	
Undetermined pain	209	54 (26.8)	153(73.2)	207 (99.0)	
Period of time pain					<0.01
Morning after wake up	215	86 (40.0)	98 (45.6)	184 (85.6)	
During day and after school	164	62 (37.8)	72 (43.9)	134 (81.7)	
Undetermined time and other	532	140 (26.3)	258 (48.5)	398 (74.8)	
Period of time pain					<0.01
Morning after wake up	215	86 (40.0)	98 (45.6)	184 (85.6)	
During day and after school	164	62 (37.8)	72 (43.9)	134 (81.7)	
Undetermined time and other	532	140 (26.3)	258 (48.5)	398 (74.8)	
Size of pain					0.03
One size	272	98 (36.0)	129 (47.4)	227 (83.4)	
Two size	261	73 (28.0)	126 (48.3)	199 (76.3)	
Transpose	236	71 (30.1)	103 (43.6)	174 (73.7)	
Other	142	46 (32.4)	70 (49.3)	116 (81.7)	
Area pain					<0.01
Occipital	163	67 (41.1)	75 (46.0)	142 (87.1)	
Parietal	499	152 (30.5)	236 (47.3)	388 (77.8)	
Frontal	137	39 (28.5)	77 (56.2)	116 (84.7)	
Other	112	30 (26.8)	40 (35.7)	70 (62.5)	

MPAH=mobile phone associated headache

Table 4. Smartphone output power group and daily dose

Variable	n	Output power (mW)			
		Minimum	Maximum	Mean	Standard deviation
Daily dose	12,696	0.00000009	1.54872780	0.0020833594	0.01623557023
Daily dose group of output power ($\times 10^{-5}$ mW)	Group 1: ≤1.79		Group 2: 1.8 to 1.99		Group 3: ≥2.0
n (%)	1,943 (15.3)		186 (1.5)		10,567 (83.2)

Table 5. Odds ratio undetermined headache and their 95% CIs for each factor and daily dose adjusted for all other factors using GEE (AR1, QIC=3303.33, QICC=3289.53)

Factor	Undetermined; mean±SD		Crude OR	Adjusted OR	95% CI		p-value
	Yes	No			Lower	Upper	
Age (year)	17±0.9	17.4±1.0	1.49	1.49	1.26	1.76	<0.01
Anxiety score	2.8±2.9	1.8±2.4	1.12	1.12	1.07	1.17	<0.01
Total	441	12,255					
	Total	Undetermined headache (%)	Crude OR	Adjusted OR	95% CI		p-value
					Lower	Upper	
Internet use: yes/no	1,416/11,280	6.2/3.1	2.07	2.33	1.71	3.19	<0.01
Hand-free use: no/frequent	10,477/951	3.6/2.6	1.50	1.92	1.11	3.29	0.02
Dose group ($\times10^{-5}$ mW): 1.80 to 1.99/≥2.00	186/10,567	5.4/ 3.3	2.82	2.32	1.23	4.34	<0.01

SD=standard deviation; OR=odds ratio; CI=confidence interval

Adjusted by age, BMI, vision, anxiety, depression, PSQI, internet use, hand free use, brand device, and smartphone output power

more likely to experience MPAH (95% CI 1.16 to 2.51) than those doing otherwise. Similarly, from our findings, ear burning sensation had a strong link with MPAH (OR_{adj} 2.43; 95% CI 1.58 to 3.72; $p<0.05$) (Figure 2).

Smartphone output power

The data on SOP was adjusted by the value of error measured from each device brand to normalize the value for all device brands. The SOP values of each day were aggregated into daily dose with an average of $2.08\pm16.2\times10^{-3}$ mW (Table 4). Apparently, minimum SOP was very low at 9×10^{-8}, while maximum SOP was 1.55 mW. Furthermore, the SOP observations were then divided into three ranged groups, equal or less than 1.79, 1.8 to 1.99, and equal or more than 2.0×10^{-5} mW. The most common range of SOP to which the samples were exposed was found to be equal or more than 2.0×10^{-5} mW, 83.2% of the observations. SOP in the 1.8×10^{-5} to 1.99×10^{-5} mW range appeared least prevalent, with only 1.5%.

Factors association with undetermined headache

To control the confounding effects, the authors conducted a statistical test to evaluate the relationship between various factors and found there were no interaction effect existed among them. Additional computations were made to adjust the effects of such potential confounders as demographic characteristics, and characteristics of smartphone use. Auto regression 1 (AR1) was set as the correlational structure due to its lowest QIC. Apparently, the SOP in 1.80×10^{-5} to 1.99×10^{-5} mW range had strongest correlation with undetermined headaches (OR_{adj} 2.32; 95% CI 1.23 to 4.34) (Table 5), which was riskier than that in equal or more than 2.00×10^{-5} mW range. The hand-free use and internet use also had strongest association with undetermined headache (OR_{adj} 1.92; 95% CI 1.11 to 3.29 and OR_{adj} 2.33; 95% CI 1.71 to 3.19). Furthermore, the factors of age and anxiety were also related with undetermined headache (OR_{adj} 1.49; 95% CI 1.26 to 1.76 and OR_{adj} 1.12; 95% CI 1.07 to 1.17).

Discussion

The result shows that the prevalent type of headache is of a TTH, 74.1%, followed by undetermined and migraine types at 16.9% and 9.0%, respectively. This is consistent with the findings from the first phase of study involving the entire student population that the prevalence of headache in the three types was 68.6, 12.3, and 18.6%, respectively, which is different from the studies conducted elsewhere. A study in Sweden (2014) using daily headache record revealed that undetermined was 31.2%[13]. Headache prevalence, of course, varies across geographic areas, cultures, and the sample group, as well as the criteria for classifying types of headache[14].

However, the prevalence of headaches in teenagers has had a tendency to increase, which is probably due to the growing varieties of stimuli or factors in daily life especially the availability of modern MPs capable of serving a diversity of needs. The MPAH prevalence (defined as MPAH equal or more than 10 times per year) reported in a study by Chu et al in 2011 among Korean teenagers was 18.9%[12], which much lower than the present study of 59.8%. Thus, the increase in MP use might contribute to a higher prevalence of headaches in teenagers.

The results revealed a difference on the characteristics of pain between MPAH and primary headache. It was found that MPAH has specific pain characteristics including short time pain, pulsing and tightening, unstable form of pain, pain often in the morning, one side headache, or pain at occipital and frontal areas, which is consistent with the study of Gogineni[4] in 2010 finding that the occipital area had the spatial peak-average specific absorption rate (SAR) (1 g) at 1.86 mW/kg. Similar to the South Korea study[12], the pains with specific characteristics could not be classified as primary headache. Furthermore, the talking mode of MP use and ear burning sensation had a statistically significant effect on MPAH, for OR_{adj} 1.71; 95% CI 1.15 to 2.44 and OR_{adj} 2.02; 95% CI 1.33 to 3.06, respectively; $p<0.01$. These findings are consistent with those of Gogineni[4], found that the talking mode emitted more power in MP than in standby mode. It showed the SAR value by comparing talking mode (0.245, 0.548, and 0.963) and standby mode (0.0245, 0.0548, and 0.0963) at 900, 1,800 and 2,200 frequencies in the Global System for Mobile communication (GSM) technology with output power 200 Mw and 20 mW, respectively[4]. This demonstrates the way in which electromagnetic radiation from MP may be a headache trigger. The electromagnetic energy is a non-ionizing radiation that can produce heat[15]. The frequeny at 900 and 1,800 MHz can increase the heat on the skin to 37.037 and 37.057 degree Celsius, respectively, and the subject would experience burning sensations around the ears[16]. The present study found no interaction effect of ear burning sensation on the relationship between typically using MP for talking and MPAH from its stratified analysis. This information is useful to investigate the smartphone electromagnetic radiation related to the undetermined headaches in the second phase.

Characteristics of smartphone use among sampled students were considered on the basis of SOP, which was measured and stored in the device and were viewed with the use of an application. SOP values in the present study were lower than the values of smartphone electromagnetic radiation in other studies that used an external metering device and might be affected upward by the radiation from other sources. The maximum SOP was 1.55 mW, which was different from the study of Lönn et al (2004) in which the most frequently used power levels were the highest at 33 dBm and the lowest at 5 dBm[17] meaning that time division multiple access (TDMA) and GSM power output values were 18.2 and 14.1 dBm. In the study of Kelsh et al[18] (2011) and Gosselin et al[19] (2010) the average output power was between 0.001 and 0.63 mW.

The undetermined headache that has specific characteristics was not classified as a primary headache like MPAH. The present findings revealed that undetermined headaches were related to SOP in 1.80 to 1.99×10^{-5} mW range (OR_{adj} 2.32; 95% CI 1.23 to 4.34). The correlation was found to be non-linear or power effect type. The present result is in agreement with the experimental studies regarding exposure to microwave frequency radiation. Those studies found that the response took place only at specific values or in a specific range. Similarly, an experimental study of Frey et al[20] found that the blood brain barrier responded to microwave frequency radiation only at 2.4 mW/cm² and 0.2 mW/cm² intensity. The mechanism of headache response to smartphone electromagnetic radiation is often driven by the dysfunction of the endogenous pain control system affecting the areas of thalamus, raphe magnus nucleus, and spinal cord by decreasing neurotransmitters such as the acetylcholine, neuronal nicotinic acetylcholine receptors playing an important role in inhibiting pain[9]. Thus, it is likely to be a trigger of MPAH. The undetermined headache that was found to be MPAH was different in clinical features from the primary headaches and should be classified as a secondary headache.

The results shown that a year younger student compared to a year older one was likely to face a relatively greater degree of undetermined headaches. This result is in contrast with most previous studies, which found headache prevalence to vary positively with age[21,22] particularly the migraine type and TTH. Previous surveys revealed as high as 31% of children aged 8 to 10 owned and used a MP[23]. A study in Korea (2013) found the average age of children first owning and using a MP decreased from 12.5 years old in 2008 to 8.4 years old in 2011, implying that there is a tendency for children to own and use a MP at a younger age[23].

Furthermore, internet use is a risk factor of undetermined headaches (OR_{adj} 1.98 to 2.41; 95% CI 1.20 to 3.51). Using smartphones in both internet and cellular modes often involve holding the device close to the head, and the electromagnetic radiation from smartphone to which the users are exposed induces the change in biological reaction, change in protein in the brain, and causes nervous system problems especially headache symptoms[5]. Electromagnetic radiation from the talking mode is nine times more intense than the listening mode[24]. The authors also found that not using a hand-free device while talking on smartphones resulted in undetermined headaches (OR_{adj} 1.92; 95% CI 1.11 to 3.29). Using a hand-free device for talking allows a distance between the telephone set and the user's head and hence results in lower exposure to electromagnetic radiation[15]. These results can be used as suggestions to prevent chronic headaches for all adolescence and students.

The headaches were reported by students and the type of headache was classified by a diagnosis algorithm, which might be one limitation of the present study. Furthermore, measuring the smartphone's output power by using the data in the smartphone, not measuring from outside, can lead to misclassification of exposure. One strong point of the present study was that it was the very first epidemiology. The tool used in the present study relied on the technology by creating a smartphone application that was used to answer the questions and collect data.

Conclusion

The undetermined headache has specific characteristics that was not classified as a primary headache like MPAH. The results revealed that SOP was related with undetermined headaches in the 1.80 to 1.99×10^{-5} mW range. The present finding confirms that undetermined headaches associated with smartphone use have specific characteristic and can be classified as secondary headaches. Moreover, younger students, internet, and no hand-free use are the risk factors of undetermined headaches. It is recommended that using a hand-free device for smartphone talk and an older age to start owning and using smartphones be suggested to prevent chronic headaches.

What is already known on this topic?

Previous study by Chu et al[12] found that MPAH could be classified as secondary headache.

What this study adds?

This report reveals that SOP was related with undetermined headaches. It confirms that undetermined headaches associated with MP use have specific characteristic and can be classified as secondary headaches.

What are the implications for public health practice?

The findings from the present study suggested that using a hand-free device for smartphone talk and an older age to own and use smartphones be suggested to prevent chronic headaches.

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Ethics approval

The present study was approved by the Institutional Review Board of the Research Ethics Committee, Faculty of Medicine, Chiang Mai University on 21 September 2014, and renewed on October 2017.

Authors' contributions

All authors conceived the design of the study, performed the statistical analyses, read and approved the final manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

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