Psychiatry Research 284 (2020) 112686

Contents lists available at ScienceDirect

Psychiatry Research

journal homepage: www.elsevier.com/locate/psychres

Review article

Association of problematic smartphone use with poor sleep quality, depression, and anxiety: A systematic review and meta-analysis

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ARTICLE INFO

Keywords:
Problematic smartphone use
Sleep quality
Depression
Anxiety
Systematic review
Meta-analysis

ABSTRACT

To quantitatively assess the association of problematic smartphone use (PSU) with poor sleep quality, depression, and anxiety, we reviewed current evidence from observational studies and performed a systematic review and meta-analysis. The EBSCO PsycARTICLES, EMBASE, PubMed and Web of Science databases were searched, and 14 studies were included for the systematic review and meta-analysis. We calculated odds risk and 95% confidence intervals (CIs), using random-effect or fixed-effect models. Heterogeneity was assessed using I^2 and chi^2 statistics. Subgroup analyses were conducted based on country, adjusted variables, the methods of statistical analysis, outcome measures and publication year. We found significantly increased risks of poor sleep quality, depression, and anxiety in people with PSU. Our findings highlight the necessity of managing the PSU. However, further studies are required to confirm the results due to the high heterogeneity and methodological limitations.

1. Introduction

In recent years, smartphones have become pervasively used globally. A Report from the Pew Research Center demonstrated that more than 2.5 billion people have smartphones. In advanced economies, such as Korea and Israel, 90% or more people own smartphones; while in emerging economies, such as Brazil and South Africa, the percentage is about 60% (Taylor and Silver, 2019). The prevalence of smartphone ownership among adults is 77% in the U.S. (Poushter et al., 2018). Smartphone is becoming a daily necessity for most people for its convenience in accessing information, social connectivity, workplace apps and entertainment (Oviedo-Trespalacios et al., 2019). Moreover, smartphones now play a critical role in the medical health field, benefiting patients and health professionals (Alosaimi et al., 2016). However, worrisome physical and psychological issues are emerging with problematic smartphone use.

Problematic smartphone use (PSU) refers to the excessive use of the smartphone or smartphone addiction in daily life, accompanied by dysfunction and symptoms similar to substance use disorder (Elhai et al., 2019). PSU is not a recognized mental disorder, but a type of non-chemical behavioral addiction involving human-machine interaction and a concept related to psychopathology (Chen et al., 2017; Panova and Carbonell, 2018). Although the PSU has been studied for decades, there is no universal consensus on its definition. Therefore, the phenomenology features of PSUs were used for its definition in this meta-analysis: (a) a strong internal drive to use the smartphone, coupled with an impaired ability to self-control; (b) increased priority given to the use of smartphones than other activities; (c) continuation of smartphone use despite negative consequences (Saunders et al., 2017). In brief, typical symptoms of PSUs include both psychological (e.g., craving, salience, and loss of control) and physical (e.g., tolerance and withdrawal) dependence (Panova and Carbonell, 2018). When a specific behavioral process was consistently rewarded, individual goal-seeking behaviors automatically triggered expectations for subsequent rewards. These automatically triggered behaviors can lead to the formation of habits, and in extreme cases, become an addiction (Neal et al., 2016). Smartphones can quickly provide salient rewards, which may develop check-up habits and lead to PSU (Harwood et al., 2014). Although individuals may spend extensive time (six hours or more per day) using their smartphones to work, study, socialize, etc., it is so productively and not likely to involve functional or serious distress (Elhai et al., 2019). Hence, the consequences cannot be categorized as PSUs without exploring the motivations and gratifications behind the rise in smartphone usage.

PSU is related to musculoskeletal pain (Xie et al., 2016), traffic and pedestrian accidents (Cazzulino et al., 2014), worse physical fitness (i.e., headaches, fatigue, dizziness, tension, memory loss, and hearing loss) (Alosaimi et al., 2016), and academic problems (Lepp et al., 2014).

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https://doi.org/10.1016/j.psychres.2019.112686
Received 12 August 2019; Received in revised form 8 November 2019; Accepted 9 November 2019
Available online 12 November 2019
0165-1781/

Moreover, there is extensive evidence demonstrating the adverse effect of PSU on mental health, such as stress (Harwood et al., 2014; Venkatesh et al., 2019), poor sleep quality (Cabre-Riera et al., 2019; Chung et al., 2018; Demir and Sümer, 2019; Dewi et al., 2018; Lee et al., 2017; Wang et al., 2019), depression (Firat et al., 2018; Kim et al., 2017, 2019, 2018), and anxiety (Hawi and Samaha, 2017; Tao et al., 2017). Explanations for the mechanisms may include: a) blue light emitted from smartphones may affect melatonin levels (Oh et al., 2015; Thomee, 2018), exposure to electromagnetic fields (e.g., smartphone usage) at night may affect the activity of the brain (especially the pineal gland) and cause changes in cerebral blood flow and brain electrical activity, leading to poor sleep quality (Demirci et al., 2015); b) PSU may cause physical discomfort, such as muscle pain and headaches, which can negatively affect sleep (Demirci et al., 2015); c) sleep is an important biological mechanism associated with mood regulation (Thomee et al., 2011), technology usage caused sleeping disruption may result in stress, depression and anxiety (Elhai et al., 2017; Lemola et al., 2015; Tao et al., 2017). Moreover, PSU may lead to depression and/or anxiety, which are associated with sleep problems (Demirci et al., 2015); d) working demands to stay digitally connected could cause stress and burnout (Derks and Bakker, 2014); e) PSU have taken up time from other health-related activities such as physical activity and supportive social interactions (Thomee, 2018).

Previous reviews investigating the correlations between PSU and mental health have preliminarily summarized the evidence from observational studies but did not quantitatively analyzed the effect size (Carvalho et al., 2018; Elhai et al., 2017, 2019; Gutiérrez et al., 2016; Thomee, 2018; Vahedi and Saiphoo, 2018). Therefore, in this systematic review and meta-analysis, we aimed to qualitatively and quantitatively investigate the association of PSU with poor sleep quality, depression, and anxiety.

2. Methods

This systematic review and meta-analysis were conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009).

2.1. . Search strategy

Two authors independently retrieved relevant studies in EBSCO PsycARTICLES, EMBASE, PubMed, and Web of Science published between 2010 and June 18, 2019. Since the iPhone 3G, debuted in 2008, started a new era of smartphones, we included studies conducted over the last 10 years to analyze data from users of smartphones rather than older cellular phones. We employed broad search terms combined with quick search and medical subject headings (MeSH) search. The search strategy used the following terms: ("smartphone" OR "cellular phone" OR "cell phone" OR "mobile phone") AND ("addiction" OR "addictive" OR "problem use" OR "problematic use" OR "Nomophobia" OR "overuse" OR "excessive use") AND ("mental health" OR "mental disorder" OR "depression" OR "anxiety" OR "sleep" OR "psychological" OR "psychopathology"). We also manually reviewed the reference lists of included studies and relevant reviews to identify potentially eligible studies.

2.2. Eligibility criteria

Studies were included if they met the following criteria: (1) original research published in English; (2) observational study (i.e., cohort study, case-control study, time-series study, or cross-sectional study); (3) used a validated scale to assess the PSU (have been widely used worldwide or have been proved to be valid through the reliability and validity tests); (4) included a standardized instrument to measure subjects' sleep quality, depression, and anxiety; and (5) odds ratios (OR), relative risk (RR), hazard ratio (HR), or prevalence ratio (PR) with 95% confidence intervals (CIs) were provided or available for calculation. We excluded studies that only investigated internet addiction, traditional telephone or landline phone addiction/excessive usage. Meeting abstracts were also excluded unless relevant results were reported or obtained from the author.

2.3. Study selection and data extraction

After removing duplicates, two authors (JY and XF) independently screened the titles and abstracts, and full-texts. Disagreements were resolved by discussion. Data were independently extracted by two authors using a predesigned table. Items extracted included study details (author, publication year, country of study, study design), participant characteristics (sample size, age, gender), PSU measures, outcome measures (sleep quality, depression, anxiety), and main findings (effect sizes with 95%CI, adjusted confounding factors). We selected the data adjusted for confounders when both the crude and the adjusted data were reported. After two authors completed the data extraction, the third author (YL) checked all the data.

2.4. Assessment of the study quality

Two authors (JY and XF) independently assessed the quality of each included study using the Newcastle–Ottawa Scale (NOS) (see Supplementary Material 1), which includes three domains (selection of participants, comparability of participant groups, and assessment of the outcome). NOS is widely used to evaluate the quality of observational studies, and two adaptations for cross-sectional studies have been reported (Finning et al., 2019; Herzog et al., 2013). NOS included

2.5. Statistical analysis

ORs with 95% CIs were used as the common measure of associations between PSU and the risk of poor sleep quality, depression, and anxiety. PRs from cohort studies and cross-sectional studies were considered equivalent to ORs for convenience. For each analysis, pooled ORs with 95% CIs were calculated using a fixed- or random-effect model, and chi-square test and I^2 statistic were used to assess the heterogeneity. The random-effect model would be used if the I^2 statistic was higher than 50%, otherwise, the fixed-effect model would be used (Higgins et al., 2003). Besides, subgroup analyses were performed by the country (developed or developing), whether adjusted for age, the methods of statistical analysis, outcome measures and publication year. Sensitivity analyses were conducted by excluding each study and rerunning the meta-analysis. To assess the risk of publication bias, the funnel plots for each outcome were firstly examined for asymmetry and then the Egger tests ($\alpha = =0.05$) were performed. Further, the trim-and-fill method would be applied if potential publication bias was detected (Duval and Tweedie, 2000). We conducted all analyses by using Stata 12.0 software (StataCorp, College Station, Texas, USA).

3. Results

3.1. Study selection and study characteristics

A total of 2366 articles were identified through our initial search, and 14 articles met the criteria were included for systematic review and 13 articles were eligible for meta-analysis (Fig. 1). Included studies were published between 2010 and 2019. Of all 14 studies, one was a cohort study and 13 were cross-sectional studies. These included studies were conducted in six different countries globally, including Korea (n = 5), Turkey (n = 3), China (n = 3), Lebanon and Iran and Spain (n = 1 each). Participants in four of the 14 studies were students at school (middle, high school, and college). For outcome measures, eight assessed sleep quality (Cabre-Riera et al., 2019; Chen et al., 2017; Chung et al., 2018; Demir and Sümer, 2019; Demirci et al., 2015;

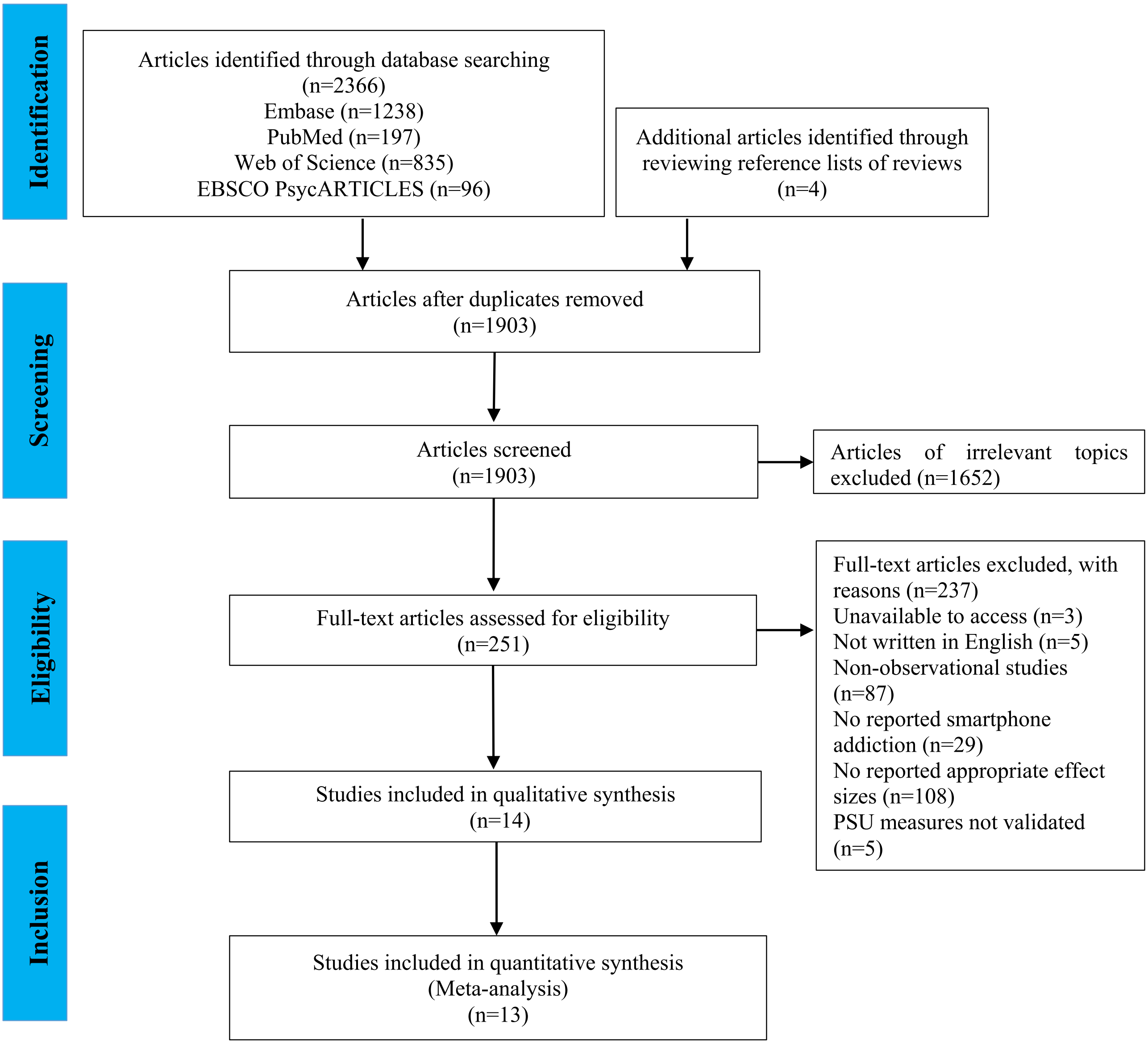

Fig. 1. Flow diagram for selection of studies (PRISMA flow diagram).

Min et al., 2017; Mohammadbeigi et al., 2016; Yang et al., 2010), seven assessed depression (Chen et al., 2017; Demirci et al., 2015; Firat et al., 2018; Kim et al., 2017, 2019, 2018; Tao et al., 2017) and six assessed anxiety (Chen et al., 2017; Firat et al., 2018; Hawi and Samaha, 2017; Kim et al., 2019, 2018; Tao et al., 2017). The PSU was measured by validated scales in each study. The outcomes were measured by using one or more tools in each study, including Pittsburgh Sleep Quality Index (PSQI), Beck Depression Inventory (BDI), Beck Anxiety Inventory (BAI), Center for Epidemiologic Studies Depression Scale (CES-D) and Self-Rating Anxiety Scale (SAS). The detailed characteristics of the included studies were shown in Table 1. The quality assessment results showed that the NOS scores for the cohort study was 8 and for the cross-sectional studies were ranged from 5 to 8 (Table S1).

3.2. Meta-analysis

Results of main meta-analysis were presented in Fig. 2. Briefly, significant association between PSU and poor sleep quality was found (OR = =2.19; 95% CI: 1.79, 2.67), with moderate heterogeneity (I^2 = =56.9%, p = 0.023) (Fig. 2(a)); PSU was associated with increased risk of depression (OR = =2.88, 95% CI: 2.30, 3.79) (Fig. 2(b)) with substantial heterogeneity (I^2 = =74.2%, p = 0.002). Also, a statistically significant association between PSU and anxiety was found (OR=3.50, 95% CI: 2.20, 5.57), while substantial heterogeneity was observed (I^2 = =86.2%, P = 0.000) (Fig. 2(c)).

3.3. Sensitivity analysis

We removed data from each study to test the robustness of the pooled results and to explore the source of the heterogeneity. In the meta-analysis of PSU exposure and poor sleep quality, the heterogeneity was decreased after the exclusion of the Chen et al. study (OR = =2.10, 95% CI: 1.85, 2.38; I^2 = =39%, P = 0.13) or the Cabré-Riera et al. study (OR = =2.37, 95% CI: 2.10, 2.68; I^2 = =43%, P = 0.10). For the association of PSU with depression, the heterogeneity was decreased when the S.G. Kim et al. study was excluded (OR = =2.47, 95% CI: 2.16, 2.83; I^2 = =31%, P = 0.21). For PSU and anxiety, the heterogeneity was decreased to undetectable levels when the Tao at al. study was excluded (OR = =4.11, 95% CI: 3.37, 5.02; I^2 = =0%, P = 0.48). Sensitivity analyses revealed no single study changed the overall results (p < 0.000) (Table 2.).

Table 1
Characteristics of studies included in the systematic review and meta-analysis.

Study	Country	Study design & sample size	Age range / mean ± SD (years)	Sex male (%)	PSU measure	Outcome	Outcome measure	Main findings & Adjusted covariates
Demir and Sümer (2019)	Turkey	C-S-S 123	18–65	19.5	MPPUS	Sleep quality	PSQI	OR = 1.696(0.425, 6.273) Habitual: PR = 1.55(1.03, 2.33) Frequent: PR = 1.67(1.09, 2.56)
Cabre-Riera et al. (2019)	Spain	P-C-S 226	17–18	47.7	MPPUS-10	Sleep quality	PSQI	Adjusted for maternal and paternal social class, maternal and paternal education level, maternal age, adolescents' characteristics and lifestyle variables (sex, age, BMI, hours of physical activity per week, caffeinated drinks intake, tobacco consumption), adolescents' current working situation (working and/or studying), adolescents' bedroom size, household size, and family structure, adolescent's chronotype, adolescents' self-perceived health-related quality of life (physical well-being, autonomy and parents, peers and social support, psychological well-being, and school environment)
Kim et al. (2019)	Korea	C-S-S 4512	14~20 15.15 ± 1.62	45.1	SAS[1]	1) Anxiety 2) Depression	1) BAI 2) BDI	**1) Anxiety:** OR = 4.406(3.438, 5.646) **2) Depression:** OR = 4.15(3.263, 5.278) Crude OR = 2.96(2.33, 3.77) Adjusted OR = 2.30(1.75, 3.02)
Chung et al. (2018)	Korea	C-S-S 1796	14.9 ± 1.8	45.7	K-SAPS	Sleep quality	PDSS	Adjusted for age, gender, caffeine intake, alcohol consumption, smoking, number of close friends, school performance, self-perceived health level, duration of a night's sleep, time of going to bed and time took to fall asleep
Kim et al. (2018)[a]	Korea	C-S-S 4516	19~49	36.86	K-SAPS	1) Anxiety 2) Depression	Subscales of the SCL-90-R	**1) Anxiety:** RR = 1.402(1.355, 1.450) **2) Depression:** RR = 1.337(1.296, 1.378) Adjusted for age, gender, marriage, income, and education
Firat et al. (2018)	Turkey	C-S-S 150	12~18 15.2 ± 1.65	41.3	PMPUS	1) Anxiety 2) Depression	Subscales of the BSI	**1) Anxiety:** OR = 6.682(2.255, 19.638) **2) Depression:** OR = 6(2.565, 13.976)
Kim et al. (2017)	Korea	C-S-S 608	22.8 ± 2.2	30.1	K-SAPS	Depression	A questionnaire to determine depression symptoms	OR = 2.00(1.35, 2.964)
Min et al. (2017)	Korea	C-S-S 608	22.8 ± 2.2	NA	K-SAS	Sleep quality	PSQI	OR = 1.99(1.33, 2.98) Adjusted for age, income, and smoking
Chen et al. (2017)	China	C-S-S 1441	17~26 19.72 ± 1.43	48.3	SAS-SV	1) Sleep quality 2) Anxiety 3) Depression	1) PSQI 2) SAS[2] 3) CES-D	**1) Sleep quality:** Male: OR = 3.668(2.608, 5.159); Female: OR = 2.734(1.978, 3.781) **2) Anxiety:** Male: OR = 2.866(1.827, 4.495); Female: OR = 4.202(2.352, 7.506) **3) Depression:** Male: OR = 2.229(1.575, 3.153); Female: OR = 2.465(1.727, 3.520)
Tao et al. (2017)	China	C-S-S 4747	19.24 ± 1.41	41.6	SQAPMPU	1) Anxiety 2) Depression	1) SAS[2] 2) CES-D	**1) Anxiety:** Crude OR = 2.69(2.28, 3.16); Adjusted OR = 2.02(1.68, 2.43) Adjusted for age, perceived family income, cigarette use, alcohol use, and Internet addiction **2) Depression:** Crude OR = 3.66(3.10, 4.33); Adjusted OR = 2.53(2.10, 3.05) Adjusted for age, perceived family income, and Internet addiction
Hawi and Samaha (2017)	Lebanon	C-S-S 381	17~27 20.84 ± 1.92	59.1	SAS-SV	Anxiety	BAI	OR = 4.706(1.511, 14.659) OR = 4.52(1.80, 11.90)
Mohammadbeigi et al. (2016)	Iran	C-S-S 363	21.8 ± 3.2	30.9	COS	Sleep quality	PSQI	Adjusted for educational level, residency place, SIM card number and using social networks
Demirci et al. (2015)	Turkey	C-S-S 248	20.5 ± 2.45	36.7	SAS[1]	1) Sleep quality 2) Depression	1) PSQI 2) BDI	**1) Sleep quality:** OR = 1.42(0.856, 2.355) **2) Depression:** OR = 3.05(1.38, 6.725)
Yang et al. (2010)	China	C-S-S 11,111	12~18 14.6 ± 1.7	49.7	PCPU-Q	Sleep quality	AIS-8	**<15 years:**; Female: OR = 2.440(1.813, 3.281) Male: OR = 3.056(1.921, 4.860)

(*continued on next page*)

Table 1 (*continued*)

Study	Country	Study design & sample size	Age range / mean ± SD (years)	Sex male (%)	PSU measure	Outcome	Outcome measure	Main findings & Adjusted covariates
								≥15 years:; Female: OR = 1.870 (1.452, 2.408) Male: OR = 2.509 (1.910, 3.300)

NA, not available; SD, standard deviation; PSU, problematic smartphone use; C-S-S, cross-sectional study; P-C, prospective cohort study; MPPUS, Mobile Phone Problematic Use Scale; SAS1, Smartphone Addiction Scale; K-SAS, Korea- Smartphone Addiction Scale; K-SAPS, Korean Smartphone Addiction Proneness Scale; PMPUS, Problematic Mobile Phone Usage Scale; SAS-SV, Smartphone Addiction Scale-Short Version; SQAPMPU, Self-Rating Questionnaire for Adolescent Problematic Mobile Phone Use; COS, Cell-Phone Over-Use Scale; PCPU-Q, Problematic Cellular Phone Use Questionnaire; PSQI, Pittsburgh Sleep Quality Index; BAI, Beck Anxiety Inventory; BDI, Beck Depression Inventory; PDSS, Pediatric Daytime Sleepiness Scale; SCL-90-R, Symptom Checklist 90 Items-Revised; BSI, Brief Symptom Inventory; SAS2, Self-Rating Anxiety Scale; CES-D, Center for Epidemiologic Studies Depression Scale; AIS-8, Athens Insomnia Scale; [a] not included in the meta-analysis.

3.4. Subgroup analyses

For subgroup analyses of the PSU and sleep quality, a significant association was observed in both developed ($N = 3$, OR = =1.95, 95%CI: 1.55, 2.75; I^2 = =35.0%) and developing countries ($N = 6$, OR = =2.42, 95% CI: 1.78, 3.29; I^2 = =58.1%). The pooled estimates were less significant among studies that adjusted for age (OR = =1.95, 95% CI: 1.55, 2.45; I^2 = =35.0%), used multivariate analysis (OR = =2.01, 95% CI: 1.57, 2.72; I^2 = =49.9%) and used PSQI to measure the sleep quality (OR = =2.12, 95% CI: 1.51, 3.00; I^2 = =68.3%). For the publication year, the association was more significant for studies published between 2016 and 2017 (OR = =2.78, 95% CI: 1.45, 2.55; I^2 = =54.4%).

For subgroup analyses of the PSU and depression, the pooled OR was 2.62 (95% CI: 2.11, 3.26) with low heterogeneity (I^2 = =34.4%) among studies conducted in developing countries. The association was more significant for studies using BDI to measure depression (OR = =4.04, 95% CI: 3.21, 5.09; I^2 = =0%), with low heterogeneity. The pooled estimate was also higher in the subgroup of studies published between 2018 and 2019 (OR = =4.27, 95% CI: 3.38, 5.38; I^2 = =0%).

For subgroup analyses of the PSU and anxiety, the pooled estimates were higher among studies that used univariate analysis (OR = =4.11, 95% CI: 3.37, 5.02), unadjusted for age (OR = =4.11, 95% CI: 3.37, 5.02), used BAI to measure the anxiety (OR = =4.42, 95% CI: 3.47, 5.63), and published between 2018 and 2019 (OR = =4.50, 95% CI: 3.53, 5.73), with decreased heterogeneity, However, a less significant associated was observed in the developing country (OR = =3.12, 95% CI: 2.05, 4.76; I^2 = =64.7).

3.5. Publication bias

The asymmetry of funnel plots indicated potential publication bias (Fig. S2). However, we observed no significant publication bias in the Egger's tests of PSU exposure and poor sleep quality ($p = 0.818$), depression ($p = 0.689$) and anxiety ($p = 0.359$) (Figure S3). Moreover, the trim-and-fill method retrieved no missing study for sleep quality and depression. The adjusted association of PSU with anxiety did not change significantly (Figure S4). The collective results indicated that the potential publication bias would not significantly affect the interpretation of the results of this meta-analysis.

4. Discussion

To the best of our knowledge, this is the first systematic review and meta-analysis attempts to quantitatively explore the association of PSU with poor sleep quality, depression, and anxiety. We found that PSU was significantly associated with increased risks of poor sleep quality, depression and anxiety.

Heterogeneity often occurs in meta-analysis (Hu et al., 2019) for the inconsistency between studies. In this meta-analysis, moderate to high heterogeneity was detected, while no individual study excessively affected the pooled estimates. Moreover, after excluding the Chen et al. study (Chen et al., 2017) and the Cabré-Riera et al. study (Cabre-Riera et al., 2019), the heterogeneity decreased to 39% and 43% in the meta-analysis of sleep quality, respectively. Cabré-Riera et al. study was the only cohort study that controlled almost all of the potential confounders by multivariate analysis. Participants were all medical college students in the Chen et al. study, and medical students are more likely to experience intensive academic performance pressure that might affect their psychological health, thereby leading to poor sleep quality (Lawson et al., 2019). In the sensitivity analysis of anxiety, the data from the Tao et al. (2017), which is the only study that adjusted for confounding factors (i.e. age, perceived family income, cigarette use, alcohol use, and Internet use), contributed significantly to the heterogeneity. It has been reported that PSU is related to age (Chen et al.,

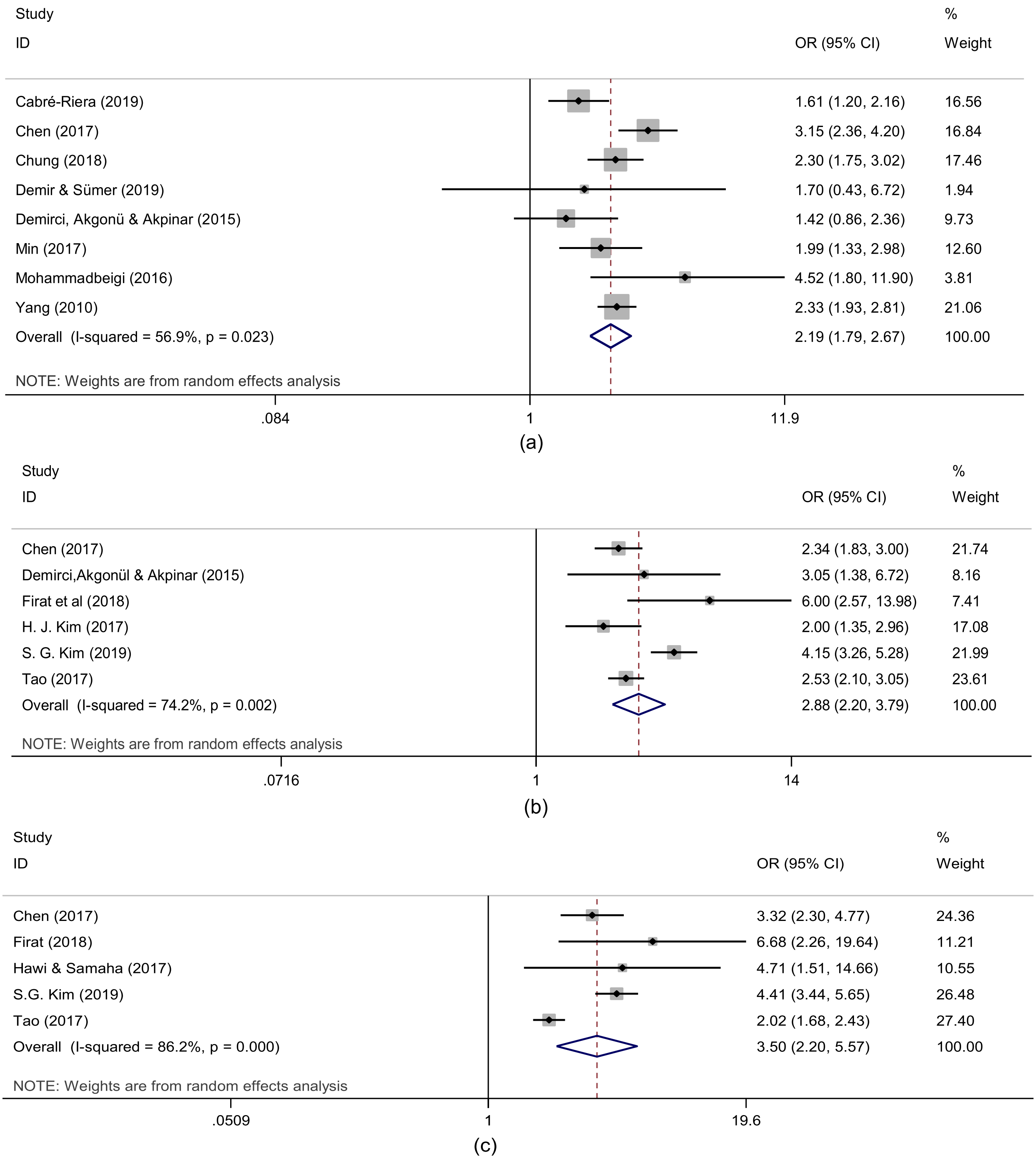

Fig. 2. Forest plot of the association between problematic smartphone use and (a) poor sleep quality; (b) depression; (c) anxiety.

2017) and Internet use (Ayar et al., 2018). Moreover, a high family income was identified as a protective factor for anxiety (Wang et al., 2016) and higher-income people were more likely to be digitally connected (Taylor and Silver, 2019).

Included studies were observational studies with different study designs. Hence, we conducted subgroup analyses to explore whether there are inconsistencies that might affect the pooled results. First, people from developed economies are more likely to own smartphones (Taylor and Silver, 2019). Our results indicated that PSU may lead to decreased sleep quality in the subgroup of developing countries (OR = 2.42 vs. 1.95). We also observed a lower risk of depression (OR = 2.62 vs. 2.93) and anxiety (OR = 3.12 vs. 4.41) in developing countries with decreased heterogeneity. Second, various scales with different cut-off scores for PSU and outcome measures were used in included studies. However, pooled estimates of different subgroups based on outcome instruments were consistent with the overall results. Third, Sleep quality is affected by many factors such as age and gender. We observed a lower risk of poor sleep quality for the subgroup controlled for age, with decreased heterogeneity. Both the macro-level (sleep duration and sleep stages) and the micro-level (sleep quality)

Table 2
Subgroup analysis of the effects of problematic smartphone use on poor sleep quality, depression, and anxiety.

Study characteristics	Poor sleep quality			Depression			Anxiety		
	N	OR (95% CI)	I^2 (%)	N	OR (95% CI)	I^2 (%)	N	OR (95% CI)	I^2 (%)
All	8	2.19(1.79, 2.67)	56.9	6	2.88(2.30, 3.79)	74.2	5	3.50(2.20, 5.57)	86.2
Country									
Developed	3	1.95(1.55,2.45)	35.0	2	2.93(1.43,5.99)	89.6	1	4.41(3.44,5.65)	/
Developing	5	2.42(1.78,3.29)	58.1	4	2.62(2.11,3.26)	34.4	4	3.12(2.05,4.76)	64.7
Outcome measurement									
PSQI/BDI/BAI	6	2.12(1.51,3.00)	68.3	2	4.04(3.21,5.09)	0.0	2	4.42(3.47,5.63)	0.0
Other/CES-D/SAS	2	2.32(1.99,2.71)	0.0	2	2.46(2.20,3.79)	0.0	2	2.62(1.76,3.90)	74.2
Other	/	/	/	2	3.24(1.11,9.43)	81.2	1	6.68(2.26,19.72)	/
Adjusted for age									
Yes	3	1.95(1.55,2.45)	35.0	5	3.04(2.09,4.42)	77.1	1	2.20(1.83,2.65)	/
No	5	2.42(1.78,3.29)	58.1	1	2.53(2.10,3.05)	/	4	4.11(3.37,5.02)	0.0
Statistical analysis									
Univariate	4	2.29(1.67,3.14)	62.0	5	3.04(2.09,4.42)	77.1	4	4.11(3.37,5.02)	0.0
Multivariate	4	2.07(1.57,2.72)	49.9	1	2.53(2.10,3.05)	/	1	2.20(1.83,2.65)	/
Year of publication									
2019~2018	3	1.92(1.45,2.55)	35.7	2	4.27(3.38,5.38)	0.0	2	4.50(3,53,5.73)	0.0
2017~2016	3	2.78(1.87,4.12)	54.4	3	2.40(2.08,2.76)	0.0	3	2.77(1.89,4.04)	61.7
≤2015	2	1.93(1.20,3.09)	69.1	1	3.05(1.38,6.73)	/	/	/	/

N, number of included studies; OR, odds ratios; CI, confidence interval; PSQI, Pittsburgh Sleep Quality Index; BDI, Beck Depression Inventory; BAI, Beck Anxiety Inventory; CES-D, Center for Epidemiologic Studies Depression Scale; SAS, Self-Rating Anxiety Scale.

structure of sleep vary with age (Mander et al., 2017) due to neurophysiological and neurochemical changes in the brainstem ascending arousal system, thalamus, hypothalamus, and specific cortical regions. Similarly, the study by Yang et al. (2010) indicated that PSU caused poor sleep quality in people under 15 years compared to people over 15 years. These results suggested that controlling confounders was important to elucidate the association. Fourth, various assessment scales for sleep quality, depression, and anxiety were used across studies, which might affect the detection rate and lead to different results. Subgroup analysis showed that different measurements have different effect sizes. Fifth, the Pew Research Center survey revealed that smartphone ownership of American has increased dramatically over the past decade from 35% in 2011 to 81% in 2019 (Anderson, 2019). From our subgroup analyses of publication year, there were higher risks of depression and anxiety among studies published recently, indicating that the rapid development of mobile technology may have contributed significantly to the link.

The association between PSU and psychological symptoms have been extensively studied in recent years. Previous systematic reviews (Elhai et al., 2017, 2019) evidenced small to moderate positive associations of PSU with anxiety and depression. In a community study (Thomee et al., 2011), PSU was associated with sleep difficulties and depression during a one-year follow-up, even after excluding participants with mental health problems at baseline. Other studies also found that PSU could significantly predict poor sleep quality (Liu et al., 2017; Wang et al., 2019). Moreover, there were extensive researches on the relevance of the Internet and technology to psychopathology, such as depression (Alhassan et al., 2018; Ng et al., press) and anxiety (Konan et al., 2018; Yang et al., 2019), which were consistent with our findings. Meanwhile, many studies on the physiological metabolism and regulation of the human body by smartphone indirectly reflected the impact of PSU on human psychology (Demirci et al., 2015; Oh et al., 2015; Thomee, 2018). Besides, experimental studies also confirmed examined relations between PSU severity and anxiety (Cheever et al., 2014; Russell B. Clayton et al., 2015). As a result, participants with severe PSU showed more anxiety after separation from the smartphone than those with mild PSU. Furthermore, researchers objectively measuring smartphone daily use found that anxiety was related to the number of smartphone screen unlocks (Rozgonjuk et al., 2018).

There were several limitations to the current meta-analysis. First, most of the included studies were cross-sectional, which may limit the establishment of a causal relationship (Elhai et al., 2019). Second, there were fewer male participants than female in most studies, leading to unequal gender distributions. The included studies also mainly focused on students who may hide their true responses, giving answers which reflect social values or professional expectations (Gutiérrez-Puertas et al., 2019). These compromised the generalizability of the findings. Third, PSU was reported by participants, and this may overestimate or underestimate their smartphone usage due to recall bias, and response-style bias. However, it seems that apps logging smartphone usage are becoming more available and thus may provide objective PSU information for future researches (Oviedo-Trespalacios et al., 2019; Thomee, 2018). Fourth, people may use smartphones in different ways and for different reasons (Oviedo-Trespalacios et al., 2019), which may contribute to the heterogeneity between participants. Fifth, many studies used univariate analysis, but important moderators such as age, perceived social support, occupational, and cultural background (Elhai et al., 2019) were not addressed. Sixth, we only focused on the association of PSU with poor sleep quality, anxiety, and depression, ignoring the interaction between poor sleep quality, anxiety, and depression, which may conversely increase the PSU as well (Chen et al., 2017; Eyvazlou et al., 2016; Kim et al., 2019). A network analysis would help understand the correlations, the underlying mediating mechanisms (Baggio et al., 2018; Liu et al., 2017) and provide strategies for protecting people from the adverse effects of PSU. Seventh, studies may have included patients suffering other risk factors that could lead to depression, anxiety or poor sleep quality. For instance, a study has shown that an unclear future is a depression risk factor for students (Mohammadbeigi et al., 2016). Therefore, future studies are encouraged to recruit more participants to reduce sample bias. Moreover, longitudinal studies are warranted to investigate mental health constructs and PSU severity at multiple time points (Elhai et al., 2019). Eighth, the number of included studies is limited due to our critical inclusion criteria, some studies assessing the PSUs using simple subjective self-report were excluded, leaving 14 studies for meta-analysis. While the criterion of PSU measure is mandatory for reducing between-study heterogeneity, it may have also caused data loss and limited the number of studies included for meta-analysis. For the current meta-analysis, we have included all studies that met our predefined inclusion criteria and quantitatively summarized the effects and provided evidence for the association. Future studies using validated scales are required for assessing the causal relationship.

PSU is becoming a global public health problem, and smartphones are double-edged swords. Increasingly, people are claiming that smartphones have been influencing a generation or that they might be making adolescents lonely and depressed (Odgers, 2018). Moreover, emerging evidence suggested that disengaging from the real world and immersing in virtual settings may induce adverse neurocognitive changes (Firth et al., 2019). Therefore, we should not only utilize the advantages of the smartphone but also reduce and avoid its adverse effects. With the younger age group of smartphone users (Taylor and Silver, 2019), it is necessary for parents and educators to help adolescents understand the impacts of PSU, and assist them in reducing the dependence on smartphones. In addition, researchers should further develop effective strategies (e.g., mindfulness) to interfere with the link between PSU and mental health problems (Yang et al., 2019). Mindfulness can not only alleviate the direct impact of PSU on sleep quality but also buffer the indirect impact through the mediation of rumination, so as to alleviate the harmful consequences of PSU (e.g., rumination and poor sleep quality) (Liu et al., 2017). Moreover, several studies have suggested the protective role of mindfulness in physical and mental health (Barnhofer et al., 2011; Pidgeon et al., 2013; Zhou et al., 2017). Also, we should encourage people to sleep regularly, exercise moderately and control smartphone use and dependence by improving self-control (Chang and Choi, 2016). Although we did not conduct stratification analysis by gender, our findings indicated the need for gender-targeted prevention and intervention strategies to reduce PSU and mental health problems as smartphone usage patterns may vary by gender (Chen et al., 2017).

The physical, mobile aspects of the smartphones facilitate PSUs by making them accessible anytime and anywhere and therefore increasing how often they are used, but the problem is not the smartphone device itself. The problems arising from smartphone usage depend on what activities the users engage in when using smartphones, the motivations to participate in these activities, and the satisfaction received from them (Panova and Carbonell, 2018). With the development of digital technology support, many smartphone intervention apps have emerged to help people regulate their smartphone usage. These apps were classified into four themes: 1) PSU diagnosis, 2) PSU intervention, 3) children use monitoring, and 4) task distraction elimination (Alrobai et al., 2019). For instance, a comprehensive Information and Communications Technology system called SAMS (Smartphone Addiction Management System) was developed for objective assessment-based diagnosis and intervention for PSU. The SAMS app was developed on Google Android-based smartphones including three features: (1) effectively monitor and store critical usage data for usage patterns, (2) provide intervention and self-control mechanism, and (3) provide analysis tools for assessing usage data to diagnose PSU (Lee et al., 2014). In addition, researchers developed a group-based intervention app for improving the self-regulation of limiting smartphone use. This app was designed to help limit usage by visualizing usage/ restriction behavior, sharing usage/ restriction information, encouraging users to participate in social competition, locking apps, and blocking notifications (Ko et al., 2015). In short, it will be important for researchers to investigate how to help users be in harmony with their smartphones. We should strive to innovate and develop a healthy, secure, and reliable smartphone app to regulate the users' behaviors and to achieve digital well-being.

In conclusion, this systematic review and meta-analysis provided evidence for positive associations between PSU and sleep quality, depression, and anxiety. The necessity of management of PSU is highlighted. Further researches should pay more attention to study settings including study design, population sampling, outcome assessment, PSU assessment methods, statistical analysis methods and control for important confounders.

Funding

This research was funded by the National Natural Science Foundation of China (NO: 81873806).

Declaration of Competing Interest

The authors declare no conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2019.112686.

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