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ORIGINAL ARTICLE

Nighttime cell phone use and sleep quality in young adults

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Abstract

Young adults are particularly vulnerable to sleep disturbances related to their cell phone use (CPU). The purpose of this study was to test Sleep Displacement and Psychological Arousal theories of CPU-led sleep disruption in relation in a sample of university students. CPU for unstructured leisure activities before sleep (CPU_BeforeBed), as well as CPU for accessing explicit or emotionally charged media content before sleep (CPU_Arousal), were both measured. 525 (75% female) undergraduate students from a large public institution participated in this study during fall 2019. The data were collected using a battery of validated self-report questionnaires. Questionnaires included the Pittsburgh Sleep Quality Index scale, which was used to measure sleep latency and sleep difficulty, and a contemporary questionnaire developed to measure CPU_BeforeBed and CPU_Arousal. A crude odds ratio analysis was implemented to analyze findings. Sleep Displacement data showed higher odds of sleep latency occurring with CPU_BeforeBed [Exp $(B) = 1.091$, $p < 0.001$]. Psychological Arousal data showed higher odds of sleep difficulty occurring with CPU_Arousal [Exp $(B) = 1.065$, $p < 0.001$]. CPU_BeforeBed significantly predicted sleep latency [Exp $(B) = 1.062$, $p < 0.01$], and CPU_Arousal significantly predicted the sleep difficulty [Exp $(B) = 1.069$, $p < 0.001$] of undergraduate students. Young adults who used cell phones before sleep and access emotionally charged content before going to bed were more likely to report trouble sleeping. They took more time to fall asleep at night as their sleep hours were compressed due to CPU. These findings support the Sleep Displacement and Arousal theories of sleep disruption and provide further insight into possible mechanisms for sleep disturbance in young adults.

Keywords Nighttime cell phone use · Sleep latency · Sleep difficulty · Arousal effects · Young adults

Introduction

Young adults (18–29 years), being the largest demographic of cell phone consumers [1], are the most vulnerable population to be influenced by adverse effects of cell phone use (CPU). One such vulnerability has been an alleged adverse effect on sleep. Excessive CPU may create sleep disruptions in young adults, which include short sleep duration, excessive daytime sleepiness, and subjective sleep quality [2], therefore, may lead to anxiety and depressive symptoms in college students [3].

The link between young adult CPU and sleep quality emerged before CPU was formalized in the research literature. In 2002, Harada et al. [4] reported that frequent CPU, especially during the night, enables young adults to be more evening-oriented and that it alters facets of their sleep (see also [5–8]). Texting and calling were the most used features of cell phones, which contributed to the majority of sleep disorders concerning CPU [9, 10]. The most recent available data suggests that nearly 83% of college students use their cell phones within 1 h of going to bed, and around 66% check cell phone notifications before getting out of bed in the morning [6].

Positive correlations between excessive CPU, sleep disturbance, and daytime dysfunction as well as a negative correlation between excessive CPU and subjective sleep quality of young adults have been found in the literature [11]. These findings suggest that young adults perceive cell phones as devices that compel them to be available round the clock, which in turn helps create sleep disturbances in them [2, 12]. Of all CPU functions, calling and texting appeared key

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contributors to substantial sleep disturbances [2]. These sleep disturbances included short sleep duration, excessive daytime sleepiness, and subjective sleep quality. Text messaging alone was found to be significantly associated with the foremost components of sleep quality: sleep latency and sleep difficulty (sleep disturbances) [13]. Interacting with cell phones before sleep may increase emotional and/or mental (cognitive) arousal, which might lead to sleep latency and sleep difficulty, and poor sleep quality. For example, CPU for unstructured leisure, especially in bed, influenced sleep variables substantially [14]. Also, playing video games before sleep was related to reduced sleep quality and longer sleep latency [15]. High CPU is linked with sleep latency, sleep difficulty, and low sleep quality thus contributing to several disorders, which may end up creating generations of sleep-deficient individuals.

Three theories were proposed to better understand the mechanism of CPU-led sleep disruption: sleep displacement theory, arousal theory, and the melatonin theory (exposure to bright light) [14, 16–18]. Although the melatonin hypothesis theory has been extensively tested [17, 19], studies on sleep displacement and arousal have not been a major focus [18]. Sleep displacement theory is based on the concept in which the use of electronic media for unstructured leisure displaces several activities including sleep [19]. Displacement of sleep happens when the brain believes it is still working because one continues to use a cell phone while in bed, creating an association in the brain between the location of CPU (i.e., the bed) and work (anything outside of sleep) [6, 14]. Arousal theory is based on the concept that the use of electronic media such as cell phones just before sleep may increase mental (cognitive), emotional or psychological arousal [17]. The media content (arousal hypothesis) concept can also be illustrated by mental (cognitive), emotional, and/or psychological arousal as the mind takes time to prepare for sleep after screen time [10, 17].

The present study, therefore, aims to (1) investigate CPU, with latest cell phone activities/operations, of current young adults using updated questionnaires (please find more details in the methods section), (2) examine the correlation of specific sleep components, such as sleep latency and sleep difficulty, with the CPU factors: CPU before bed and CPU arousal, (3) aid in understanding of how and why nighttime CPU may influence sleep latency, sleep difficulty by providing theoretical support to the established correlations of examined variables.

Hypotheses

The hypotheses for the study are as follows:

H1: We expect, according to sleep displacement theory, the CPU for unstructured leisure activities before sleep are related to increased sleep latency of undergraduate students;
H2: We expect, according to arousal theory (media content), CPU for accessing sexually explicit, violently explicit, or emotionally charged media content before sleep to relate positively to the sleep difficulty (sleep disturbance) of undergraduate students.

Methods

Participants

The sample ($N = 525$) consisted of undergraduate students between 18 and 50 years old, with an average age of 20 years ($SD = 3.18$). In the study sample, 98% of the participants were between the age of 18 and 30, with 2% of the participants between the age of 31 and 50 years. From this sample, 75% of the participants were female, 24% male, and 1% of the participants preferred not to answer. It was an ethnically diverse sample of participants comprising 49% Caucasian, 24% Latinx, 19% Asian, 3% African American, 1% Native American, while 3% identified as "other" in the survey. The remaining 1% preferred not to answer.

The respondents were from fourteen different colleges and majors, including the College of Engineering (29%), the College of Agriculture and Life Sciences (17%), the College of Liberal Arts (16%), the College of Science (9%), the College of Education and Human Development (9%), Mays Business School (7%), and the College of Veterinary Medicine and Biomedical Sciences (7%). The sample was also diverse in terms of the number of years the participants attended a 2-year or 4-year higher institution. It included 38% incoming freshman, 19% sophomore, 17% junior, 14% senior, and 13% returning senior. Our sample was largely reflective of the university population with the margin of error of ±4.25% at a 95% confidence level.

Procedures

An online quantitative survey was designed using psychometric principles aligned with best practices for constructing an online assessment tool [20, 21]. All enrolled undergraduate students, with no severe mental health problems at the time of taking this survey, were invited for voluntary participation by email invitations distributed through the university's listserv. The link on the invitation email would take the invitees to an online survey software (Qualtrics) webpage. This webpage would have informed consent, required from undergraduate students, on the first page. Prospective participants were able to read all the necessary information regarding their participation in the study before electronically signing the informed consent. Those who submitted their informed consent by clicking the "I Agree" button got access to the survey. The survey was compatible with mobile devices as it was presumed students with high cell phone use would prefer this interface method.

Measures

Sleep questionnaire

To measure sleep latency and sleep difficulty, the 19 item Pittsburgh Sleep Quality Index (PSQI) scale was used. The PSQI scale is a standardized clinical instrument, which has strong internal consistency (Cronbach's alpha = 0.83) and test–retest reliability ($r = 0.85$) [22]. Moreover, the structurally valid "three-factor model (i.e., sleep efficiency, sleep latency, and sleep quality)" indicated that PSQI is an effective measure for assessing sleep quality factors such as sleep latency and sleep difficulty separately [23]. The reliability of the PSQI was assessed using the sample from the current study ($N = 525$; 75% female), and the items were found to exhibit strong internal consistency (Cronbach's alpha = 0.81).

Sleep latency was measured by combining the scores of questions 2 and 5a of PSQI: Q2) During the past month, how long (in minutes) has it usually take you to fall asleep each night (Scoring: "15 min"—0, "16–30 min"—1, "31–60 min"—2, "> 60 min"—3), Q5a) During the past month, how often have you had trouble sleeping because you cannot get to sleep within 30 min (Scoring: "Not during past month"—0, "Less than once a week—1, "Once or twice a week—2, "Three or more times a week"—3). The combined scores from both the items were translated into categorical variables as follows: "sum of Q2 and Q5a = 0"—0, "sum of Q2 and Q5a = 1–2"—1, "sum of Q2 and Q5a = 3–4"—2, "sum of Q2 and Q5a = 5–6"—3 [22].

Sleep difficulty was measured by combining the scores of questions 5b to 5j of PSQI: Q5) During the past month, how often have you had trouble sleeping because you b) Wake up in the middle of the night or early morning, c) Have to get up to use the bathroom, d) Cannot breathe comfortably, e) Cough or snore loudly, f) Feel too cold, g) Feel too hot, h) Have bad dreams, i) Have pain, j) Other reason(s), please describe (Scoring: "Not during past month"—0, "Less than once a week—1, "Once or twice a week—2, "Three or more times a week"—3). The sum of the scores of items 5b to 5j were translated into categorical variables as follows: "sum of 5b–5j = 0"—0, "sum of 5b–5j = 1–8"—1, "sum of 5b–5j = 10–18"—2, "sum of 5b–5j = 19–27"—3 [22].

Sleep duration was also assessed in addition to sleep latency and sleep difficulty. Question 4 of PSQI provided sleep duration, and the scores were translated into categorical variables as follows: Q4) During the past month, how many hours of actual sleep did you get at night? (This may be different from the number of hours you spend in bed.) (Scoring: "> 7 h"—0, "6–7 h"—1, "5–6 h" —2, "< 5 h"—3).

CPU questionnaire

To answer our diverse set of research questions related to CPU in different situations, completely relying on a patchwork of extant questionnaires on CPU would not fit our purposes. We developed a comprehensive survey to ensure our questions were up-to-date, suited to our research questions, sensitive to the academic context, and consistent in format and presentation. In doing so, we adhered to using psychometric principles aligned with best practices for constructing an online assessment tool [20]. The vast majority of our items were adapted from existing scales though a number of scales were extended and the language was modified to make them clearer and more understandable.

Translational validity was assessed using face and content validity [24, 25]. To test the face validity, the survey was administered to two professional development specialists from the Center for the Advancement of Literacy & Learning at the university. The feedbacks from both the specialists were implemented in the instrument. To test content validity, faculty experts from the department of English and the Department of Communication were contacted to review the final draft of the instrument. Two reviewers, one from each department, have reviewed the instrument and evaluated the instrument positively.

The internal consistency of the items was measured for subscales using the sample from the current study ($N = 525$; 75% female). The first subscale, i.e., CPU_BeforeBed, consisted of nine items, with a minimum possible score of 9 and a maximum possible score of 36. All the items in the CPU_BeforeBed construct were found to exhibit good internal consistency (Cronbach's alpha = 0.76). The second subscale, i.e., CPU_Arousal, consisted of six items, with a minimum possible score of 6 and a maximum possible score of 60. All the items in the CPU_Arousal construct were also found to exhibit good internal consistency (Cronbach's alpha = 0.70). The overall scale consisted of strong reliability (Cronbach's alpha = 0.75) for the designated sample. Before administering the main study, the internal consistency of the items was tested in two separate pilot studies (refer to "Appendix A" for more details). For each of the CPU subscales, we provide a detailed account of the modifications and sources that were used in the supplements (see "Appendix B").

Data analysis

The statistical package SPSS for Windows (Version 25.0, Chicago, IL, USA) was used for all analyses. Ordinal logistic regression was used to compute the correlation between CPU variables (CPU_BeforeBed and CPU_Arousal) and Sleep variables (sleep latency and sleep difficulty). To maintain rigor and quality in the outcomes, a control analysis was also administered for the dependent variables prior to conducting main analyses. The control analysis consisted of the test of ceiling and floor effect for the study variables. The control analysis also consisted of the test of multicollinearity and the test of proportional odds for sleep latency, sleep difficulty, and sleep duration. One way ANOVA and post-hoc analyses were used to see the difference between the groups, and the significance level was set as 0.01 for the analyses. The partial eta squared was used to determine effect size between the groups (significance level = 0.01) because this method takes all level categories into account [26, 27]. For a univariate ANOVA, the effect size for the outcome variable with a partial eta squared value of 0.01 is considered small, 0.06 is considered medium, and 0.14 is considered large [27].

Table 1 The descriptive statistics of continuous variables age, CPU_BeforeBed, CPU_Arousal, Bedtime, and Wake-up time (*N* = 525)

	Minimum	Maximum	Mean ± SD	Mode
Age	18	50	20 ± 3.18	18
CPU_BeforeBed	9	36	18 ± 4.32	17
CPU_Arousal	6	54	16 ± 8.38	6
Bedtime	0	23.30	7.34 ± 10.02	0
Wake-up time	4.30	12.00	7.54 ± 1.23	7

CPU_BeforeBed the use of cell phone before sleep, *CPU_Arousal* the use of cell phones for accessing sexually explicit, violently, or emotionally charged media content

Results

Descriptive statistics

While the undergraduate students reported occasionally (infrequently but not compulsively) using cell phones before bed on a scale ranging from 9 to 36, with 9 being "Never" and 36 being "Always", they reported having arousal due to the use of cell phones on a scale ranging from 10 to 60, with 10 being "not common at all" and 60 being "extremely common" (Table 1). The majority (87%) of undergraduate students have usually gone to bed between 10.30 p.m. and 2 a.m., with the bedtime distribution as follows: 3.5% gone to bed before 10 p.m., 15.5% gone to bed between 10 and 11 p.m., 29% gone to bed between 11 p.m. and 12 a.m., 26% gone to bed between 12 and 1 a.m., 17% gone to bed between 1 and 2 a.m., and 9% gone to bed between 2 and 5 a.m. From the study sample, 79% of undergraduate students have usually gotten up between 6 and 10 a.m., with the wake-up time distribution as follows: 10% woke up before 6 a.m., 27% woke up between 6 and 7 a.m., 26% woke up between 7 and 8 a.m., 21% woke up between 8 and 9 a.m., 12% woke up between 9 and 10 a.m., and 4% woke up between 10 a.m. and 12 p.m.

While more than one quarter (27%) of students scored 0 on 2 sleep latency questions (i.e., falling asleep less than 15 min and having no difficulty getting to sleep within 30 min), a small percentage (5%) of undergraduate students reported no sleep difficulty (Table 2). On one hand, three-quarters (73%) of undergraduate students reported low, moderate, or high sleep latency, with some sort of trouble sleeping during the past month. On the other hand, 95% of undergraduate students reported having some sort of sleep difficulty, with 21% of them having trouble sleeping once or twice and for three or more times a week. Further, more than three-quarters (78%) of undergraduate students reported reduced sleep duration, with 21% of them having either 5–6 h or less than 5 h of sleep during the past month.

Table 2 The descriptives of categorical variables: sleep latency, sleep difficulty, and sleep duration (*N* = 525)

Sleep latency			Sleep difficulty			Sleep duration		
Scores	Frequency	Percent	Scores	Frequency	Percent	Scores	Frequency	Percent
0	141	27	0	28	5	0	116	22
1	195	37	1	379	72	1	302	57
2	122	23	2	111	21	2	78	15
3	67	13	3	7	2	3	29	6
Total	525	100		525	100		525	100

For sleep latency: 0—"15 min or less," 1—"16–30 min," 2—"31–60 min," and 3—"more than 60 min". For sleep difficulty: 0—"not during the past month," 1—"less than once a week," 2—"once or twice a week," and 3—"three or more times a week". For sleep duration: 0—"> 7 h," 1—"6–7 h," 2—"5–6 h," 3—"< 5 h"

Table 3 Ordinal logistic regression analyses showing correlation between CPU variables (CPU_BeforeBed and CPU_Arousal) and sleep variables (sleep latency, sleep difficulty, and sleep duration) ($N = 525$)

Dependent variable	Independent variable	Odds ratio	
		Crude OR (95% CI)	Adjusted OR (95% CI)[a]
Sleep latency	CPU_BeforeBed	1.091 (1.050–1.134)**	1.062 (1.021–1.105)*
Sleep difficulty	CPU_Arousal	1.065 (1.042–1.089)**	1.069 (1.043–1.096)**
Sleep duration	CPU_BeforeBed	1.096 (1.053–1.140)**	1.091 (1.048–1.135)**
	CPU_Arousal	1.033 (1.012–1.053)*	1.037 (1.016–1.059)**

CPU_BeforeBed the use of cell phone before sleep, *CPU_Arousal* the use of cell phones for accessing sexually explicit, violently, or emotionally charged media content

[a] Adjusted for sex, ethnicity, colleges, age, years in college, the use of sleep medication, CPU_BeforeBed, and CPU_Arousal

*$p < 0.01$; **$p < 0.001$

Inferential analysis

An ordinal logistic regression was conducted to analyze the correlation between CPU variables and sleep quality variables (Table 3). The independent and dependent variables passed tests of multicollinearity and proportional odds. The location parameters were not the same across response categories for both sleep latency ($p = 0.682$), sleep difficulty ($p = 0.927$), and sleep duration ($p = 0.729$), which meant the relationships were consistent across ranks on sleep latency, sleep difficulty, and sleep duration. The variable mental health problem was one of the exclusionary criteria for this study, therefore, the impact of mental health problem on outcome variables was ruled out.

H1 was supported. The crude odds ratio showed that there were higher odds of sleep latency occurring with the exposure to the use of cell phones for unstructured leisure activities before sleep (CPU_BeforeBed) [Exp (B) = 1.091, $p < 0.001$] (Table 3). This equaled a one standard deviation unit increase in CPU_BeforeBed to predict a 4.59 point increase in sleep latency as described by the adjusted odds ratio. Sex, age, ethnicity, years in college, and the use of sleep medication were adjusted in the model. These variables were added because they have all been related to sleep quality in the literature [28]. More specifically, women tend to report poorer sleep quality than men [29], older individuals report poorer sleep quality than younger people [29], people from certain ethnic backgrounds, such as White**,** report better sleep quality than people from racial/ethnic minorities [30], and finally, increase in sleep medication use has been associated with years in college [31]. In the present study, the odds of having longer sleep latency were increased by 6.2% after adjusting the variables sex, ethnicity, age, years in college, and the use of sleep medication assuming the variable CPU_BeforeBed is kept constant.

CPU_BeforeBed parameters were not the same across sleep latency categories as the assumption of proportional odds was found to be satisfied ($p = 0.682$). The model significantly fits the null model [Omnibus test χ^2 (12) = 22.519, $p < 0.01$], and controlling other variables improved the ability to predict the correlation. CPU_BeforeBed was found as a significant predictor of the sleep latency [Exp (B) = 1.062, $p < 0.01$] and had a medium effect on the sleep latency of undergraduate students [F (24, 500) = 1.965, $p < 0.01$, partial eta squared = 0.09].

The crude odds ratio also showed that there were higher odds of reduced sleep duration occurring with the exposure to the use of cell phones for unstructured leisure activities before sleep (CPU_BeforeBed) [Exp (B) = 1.096, $p < 0.001$] (Table 3). This equaled a one standard deviation unit increase in CPU_BeforeBed to predict a 4.71 point increase in reduced sleep duration as described by the adjusted crude odds ratio. The model significantly fits the null model [Omnibus test χ^2 (5) = 27.44, $p < 0.001$], and controlling other variables improved the ability to predict the correlation. CPU_BeforeBed was found as a significant predictor of the reduced sleep duration [Exp (B) = 1.058, $p < 0.01$] and had a medium effect on the sleep duration of undergraduate students [F (24, 500) = 2.233, $p < 0.001$, partial eta squared = 0.10].

H2 was also supported. The crude odds ratio showed that there were higher odds of sleep difficulty occurring when cell phones were used for accessing sexually explicit, violently explicit, or emotionally charged media content before sleep (CPU_Arousal) [Exp (B) = 1.065, $p < 0.001$] (Table 3). This meant that a one standard deviation unit increase in CPU_Arousal predicted a 8.92 point increase in sleep difficulty as described by the adjusted odds ratio. In this model, the odds of having sleep difficulty were increased by 6.9% after adjusting the variables sex, ethnicity, age, years in college, and the use of sleep medication, assuming the variable CPU_Arousal is kept constant. CPU_Arousal parameters were independence across all the sleep difficulty categories within the model (as $p = 0.927$). However, the model improved the ability to predict the correlation between CPU_Arousal and sleep difficulty [Omnibus test chi-square (12) = 60.694, $p < 0.001$], and the CPU_Arousal significantly predicted the sleep difficulty of undergraduate students [Exp (B) = 1.069, $p < 0.001$]. The effect size for CPU_Arousal was statistically significant [F (38, 486) = 1.976, $p < 0.01$], and CPU_Arousal had a medium effect on the sleep difficulty of undergraduate students (partial $\eta^2 = 0.13$).

The crude odds ratio also showed that there were higher odds of reduced sleep duration occurring when cell phones were used for accessing sexually explicit, violently explicit, or emotionally charged media content before sleep (CPU_Arousal) [Exp (B) = 1.033, $p < 0.01$] (Table 3). This meant that a one standard deviation unit increase in CPU_Arousal predicted a 8.69 point increase in reduced sleep duration as described by the adjusted crude odds ratio. The model significantly fits the null model [Omnibus test χ^2 (5) = 21.244, $p < 0.001$], and controlling other variables improved the ability to predict the correlation. CPU_Arousal was found as a significant predictor of the reduced sleep duration [Exp (B) = 1.024, $p < 0.05$]. However, the effect size for CPU_Arousal was not statistically significant [F (38, 486) = 1.155, $p = 0.247$, partial $\eta^2 = 0.08$].

Discussion and conclusion

Concerning our first hypothesis, the odds ratio for sleep latency was statistically significant, positive, and with a medium effect size. Further, our sleep latency data showed that 73% of undergraduate students had significant levels of sleep latency, with 36% on a higher-end who either could not sleep within 1 h or for more than 1 h after going to bed at night. This means that the use of cell phones after a target bedtime could have resulted in higher risks of sleep latency in undergraduate students, which means they took more time than usual to fall asleep after going to bed. Moreover, sleep duration data showed that 78% of undergraduate students slept for 7 h or less, 2–3 h less than the recommended amount for young adults [32]. CPU-led sleep latency can be attributed to these reduced hours of sleep. Putting everything together, undergraduate students who used cell phones after a target bedtime were at higher risk of sleep latency, thus had reduced sleep hours.

These data were in line with previous results of other studies [6, 33], which revealed that CPU ‘in bed’ and CPU ‘after lights were out’ negatively influenced sleep quality as measured by indices such as sleep latency. Studies have found that text messaging alone impacted the sleep latency of undergraduate students and was found to be the mediator between CPU and sleep-related disorders, such as depression and anxiety [3]. It is possible these effects are due to the psychological effects of sleep displacement [14]. The mind, using the cellphone in bed, would associate the location of CPU (e.g., the bed) with activities typically conducted during the day (e.g., work, socializing, play, etc.) which could increase sleep latency. Our study supported the sleep displacement mechanism of sleep disruption proposed in previous studies [14, 16, 18].

Concerning our second hypothesis, the odds ratio for sleep difficulty was statistically significant, positive, and with a medium effect size. Further, we found that undergraduate students reported experiencing CPU_Arousal, which escalated sleep difficulty in them. The data showed that 95% of undergraduate students had some sort of sleep difficulty, with 21% having trouble sleeping once or twice a week, and 72% having trouble sleeping less than a week. From the whole sample, 2% of undergraduate students reported trouble sleeping three or more times a week. These data align with the previous studies on college students reporting sleep difficulty due to the use of cell phones on the bed [2, 12, 14, 29]. Sleep duration data showed that 78% of undergraduate students had reduced hours of sleep. CPU-led sleep difficulty can be attributed to these reduced hours of sleep. Putting everything together, undergraduate students who used cell phones for accessing emotionally charged media content were at higher risks of sleep difficulty, thus had reduced sleep hours.

Arousal Theory can help explain CPU-led sleep difficulty in undergraduate students. As per the theory, the development of psychological arousal happens because of accessing sexually explicit, violently explicit, or emotionally charged media content before sleep. These are stimuli that would typically require one’s full wakefulness as they carry evolutionary/survival value. Undergraduate students might have been engaged in accessing emotionally charged media content such as playing video games, emotionally charged chatting, pornography, etc. before sleep resulting in sleep difficulty. These results resonate with the previous studies, which reported a close connection between psychological arousal due to the use of electronic media before bed and sleep difficulty [14, 16, 34]. Bringing everything together, an increase in the use of cell phones for accessing sexually explicit, violently explicit, or emotionally charged media content before sleep was associated with increased sleep difficulty of undergraduate students.

To the best of our knowledge, our study was the first to measure CPU_Arousal and the correlation between CPU _Arousal and sleep difficulty of undergraduate students. Previous studies investigated texting, calling, and social networking, [6, 14, 35] but did not investigate violently explicit or emotionally charged media content before sleep. Cain and Gradisar [16] suggested that the use of electronic media, such as cell phones, just before sleep escalates mental (cognitive), emotional or psychological arousal. The feeling of constant connectivity was also found as one of the key reasons that compelled young adults to be available "around the clock," even after going to bed at night [36]. Results from this study indicated that interacting with cell phones before sleep escalated emotional and/or mental (cognitive) arousal in undergraduate students and it is possible that, according to the sleep-arousal hypothesis, this contributed to their increased sleep difficulty.

Limitations

While this study has produced several novel and practical findings, there are limitations to be considered when interpreting the results. The sample, comprised of undergraduate students from a single public university in the Southwestern United States, may reflect some socio-economic and cultural specificities of university students from the Southwestern region. The outcomes may have limitations for non-college CPUsers from the young adult demographic as the sample included traditional undergraduate students. The sample also suffered from over-representation, especially for female participants (75%). Given the numerous factors influencing the relationship between sleep and cell phone use, it is possible unmeasured factors could confound the present study. The measures relied on self-report which lead to another limitation of this study. Recall bias is the key concern about self-reported questionnaires; however, other factors occurring while participants took the survey including living, non-academic workload, studies, leisure activities, family, and social commitments cannot be ruled out. It is argued that "subjective measures can sometimes provide accurate and efficient assessments of objective states," such as physical functioning [37]. However, subjective self-reported measures may have limitations due to a number of reasons, such as honesty/image management, introspective ability, understanding, rating scales, response bias, and sampling bias [38]. Finally, due to the correlational nature of the study, causality cannot be inferred from the results.

Recommendations

Both subjective (quantitative surveys, reflections, sleep diaries, etc.) and objective (clinical assessments, embedded sensors, and built-in cell phone sensing apps) assessment methods should be used to gain a detailed, comprehensive, and in-depth understanding of CPU. The cell phone operating system records (i.e., physical activity, social interaction, mobility, sleep, and CPU) could also be used to better understand CPU behaviors. Diverse and representative samples from both college and non-college settings and across majors should help see the difference in CPU patterns across young adult demographics. More quantifiable measures using the latest cell phone activities/operations will help assess changing trends in CPU over time. Linking CPU measures/variables or CPU activities/operations to existing theories will help provide a theoretical basis to CPU research. Having a study done to determine if quarantine has impacted CPU, sleep quality, and arousal is warranted.

Appendix A

Scale reliability

Various measures were taken to test the scale reliability. The Kaiser–Meyer–Olkin (KMO) measures of sampling adequacy were administered to see the loading of the items within the constructs. All nine items from the construct of CPU_BeforeBed (KMO = 0.79, $p < 0.001$) and all six items from the construct of CPU_Arousal (KMO = 0.59, $p < 0.001$) loaded well within the constructs, as determined by the KMO measures. A statistically significant KMO above 0.5 indicates that each item loads well on a designated construct. Greater KMO (> 0.5) specifies better loading. The KMO's for both constructs were statistically significant ($p < 0.001$). Two pilot studies [Study 1 (Spring 2019; $n = 32$; undergraduate students; 78% female); Study 2 (Fall 2019; $n = 78$; undergraduate students; 84% female)] were conducted to gauge various factors including the time required for completion of the survey. All items in the instrument were found to exhibit good internal consistency [Cronbach's alpha = 0.74 (spring 2019 study); Cronbach's alpha = 0.71 (fall 2019 study)] in both pilot studies.

Appendix B

CPU_BeforeBed measures

Nine items were used to accurately gauge the use of cell phones at night during the past month. The CPU activities assessed were the following: calling, texting, emailing, listening to Podcasts or listening to music, paying attention to cell phone notifications, using social media (Instagram, Twitter, Snapchat, Facebook, LinkedIn, etc.), watching videos (Netflix, Hulu etc.), gaming, non-social media internet browsing (Shopping, surfing, etc.), and all other uses, driven by apps and software not listed above. From the nine items, on a Likert scale from '*never*' to '*always,*' 8 items were adapted from a CPU_Night Scale [39] (Cronbach's alpha = 0.81). One item was written by the researcher in similar lines as that of other items to gauge the disruption due to cell phone notifications after going to bed at night. The experimenter-added question was “In the last 30 days, have you been awakened by cell phone notifications after going to bed at night?” Authors Li et al. employed a 5-point Likert scale (i.e., 1—"Never", 2—"Only Occasionally", 3—"Occasionally", 4—"Often", and 5—"Always"). To have clarity in responses, one point (i.e., 2—"Only Occasionally") was removed for the present study.

The total score on the instrument ranged from 9 to 36 with a higher score indicating higher CPU before sleep. A few modifications were made to the original items in terms of including more cell phone activities, such as listening to Podcasts. Necessary linguistic alterations were also made to some of the items to make the meaning of those items clearer. For example, “sending or receiving” was mentioned in parentheses for texts, “receiving, writing, sending” for emails, “Shopping, surfing, etc.” for internet browsing, and “Instagram, Twitter, Snapchat, Facebook, LinkedIn, etc.” for social media CPUsage.

The final CPU_BeforeBed items were as follows:

1. In the last 30 days, have you been awakened by cell phone calls after going to bed at night?
   Never Occasionally Often Always.
2. In the last 30 days, have you been awakened by cell phone texts after going to bed at night?
   Never Occasionally Often Always.
3. In the last 30 days, have you been awakened by cell phone notifications after going to bed at night?
   Never Occasionally Often Always.
4. In the last 30 days, have you stayed up late to use your cell phone for calling after a target bedtime?
   Never Occasionally Often Always.
5. In the last 30 days, have you stayed up late to use your cell phone for texting (sending or receiving) after a target bedtime?
   Never Occasionally Often Always.
6. In the last 30 days, have you stayed up late to use your cell phone for emailing (receiving, writing, sending) after a target bedtime?
   Never Occasionally Often Always.
7. In the last 30 days, have you stayed up late to use your cell phone for listening to Podcasts or listening to music after going to bed at night?
   Never Occasionally Often Always.
8. In the last 30 days, have you stayed up late to use your cell phone for social media (Instagram, Twitter, Snapchat, Facebook, LinkedIn, etc.) activities after a target bedtime?
   Never Occasionally Often Always.
9. In the last 30 days, have you stayed up late to use your cell phone for watching videos (Netflix, Hulu, etc.), gaming, non-social media internet browsing (Shopping, surfing, etc.), and all other uses, driven by apps and software after going to bed at night?
   Never Occasionally Often Always

CPU_Arousal measures

Six items were used for assessing CPU_Arousal. The first three items were meant to assess participants’ engagement with their cell phones on a Likert-based scale (from 1 to 10) towards emotionally charged texts and messages, explicit content pertaining to sexuality (pornography, tinder, dating sites, etc.), and explicit content pertaining to violence (video games, movies, etc.). The remaining three items, on a Likert-based scale (from 1 to 10), were intended to assess the rate of occurrence of uses mentioned in the first three items that keep participants awake. Total score range from 6 to 60 with a higher score indicating extremely common to engage in emotionally charged texts and images and explicit content pertaining to sexuality and violence with the constant occurrence of being awake by engaging in these activities.

For CPU arousal items, a base question regarding engagements in an arousal activity was adapted from the Sexual Media Diet (SMD) Scale developed by Brown et al. [34] (Cronbach’s alpha = 0.83). The SMD scale was constructed to capture “the overall proportion of sexual content in the adolescents’ media diet in 4 media over a 1-month period at baseline.” The base question from Brown et al. [34] was modified and was extended to six items, mirroring the CPU_BeforeBed items derived from Li et al. [39]. The cell phone operation/activity sexting (i. e., emotionally charged texts and messages) was adapted from Fleschler Peskin et al. [40], and the activities to engage in explicit content pertaining to sexuality and violence were adapted from Dill, Gentile, Richter, and Dill [41]. Dill et al. [41] have provided a detailed content analysis of the items used for engaging with explicit content pertaining to sexuality and violence in video games.

The final CPU_Arousal items were as follows:

(i) In the last 30 days, how common is it for you to use your cell phone to engage in:

(1 = not common at all/10 = extremely common)

1. Emotionally charged text messages and images.

1 2 3 4 5 6 7 8 9 10

2. Explicit content pertaining to sexuality (pornography, tinder, dating sites, etc.)

1 2 3 4 5 6 7 8 9 10

3. Explicit content pertaining to violence (video games, movies, etc.)

1 2 3 4 5 6 7 8 9 10

(ii) In the last 30 days, rate how common it is for you to be kept awake by engaging in the following cell phone activities OR by thinking about occurrences earlier in the day.

(*Note: For this question, Never/Rarely = Not even once/only when required; Occasionally = Infrequently but not compulsively; Often = Regularly but not constantly; Always = Constantly)

1. Reading or responding to emotionally charged text messages and images

Never Occasionally Often Always

2. Sexually oriented apps, multimedia, or related materials

Never Occasionally Often Always

3. Violence-based apps, games, multimedia, or related materials

Never Occasionally Often Always

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Declarations

Conflict of interest The author(s) report no conflict of interest.

Ethical approval This study was reviewed and approved by the Institutional Review Board (IRB) of Texas A&M University (IRB2019-0980M) under the 45 CFR 46.104 declaration of the Human Research Protection Program (HRPP) of the University. All the procedures in the study involving human participants were performed in accordance with the IRB and HRPP standards.

Informed consent An informed consent was obtained from all the participants included in the study.

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