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Digital media use in the 2 h before bedtime is associated with sleep variables in university students

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ABSTRACT

Digital media use is widespread in University students, and use of digital media near bedtime has a broadly negative effect on sleep outcomes. Adequate and good quality sleep is important for physical and mental health, but few studies have rigorously measured both sleep and digital media use. In this study, we investigated whether self-reported sleep patterns were associated with digital media use in a first-year University student (N = 254, 48% male) population. Students tracked their sleep through daily online diaries and provided digital media use data in 15-min blocks for 2 h prior to bedtime on nine occasions. A longer duration of digital media use was associated with reduced total sleep time and later bedtime, while greater diversity of digital media use was associated with increased total sleep time and earlier bedtime. Analysis of activities in the last hour before bedtime indicated that activity type plays a role in digital media's effect on sleep, with computer work, surfing the Internet, and listening to music showing the strongest relationship to multiple sleep variables. These findings have implications for physical and mental health of University students and can inform design of devices to minimize negative effects of digital media on sleep.

1. Introduction

Young adults rely heavily on digital media devices to complete many daily tasks, and this use is likely to interact with their daily activities, including sleep. Sleep is important for health, academic outcomes, and daily functioning in University students. Researchers in the fields of sleep research and human computer interaction (HCI) have documented interactions between sleep or daily rhythms[1] and digital media in University students. Sleep researchers have used experimental and self-report studies to test relationships in University students between particular digital media types and sleep. HCI researchers have used mixed methods, combining varying combinations of computer and phone logging, biosensors, experience sampling, and surveys to investigate stress and multitasking related to daily rhythms in this population, and also to perform empirical studies of prototype phone applications (apps) for tracking sleep. Although the literature from these two fields indicates a negative relationship between digital media use and sleep/daily rhythms, what is missing is time and activity-specific analysis of digital media use in relation to rigorously collected information about sleep timing and quality. This paper adds to the literature by reporting on a study of digital media use near bedtime that was part of a larger study of sleep and depression vulnerability among normal University students.

Our focus on University students in this paper is important because increasing age and independence from parental restrictions may result in fewer restrictions on digital media. University students also tend to report poor sleep (e.g., Lund, Reider, Whiting, & Prichard, 2010). Given that digital media use plays a central role in the lives of University students, and many students report poor sleep both in terms of quantity (hours slept) and quality

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[1] Although these terms are not synonymous, they are put together here because sleep scientists typically report sleep outcomes while human–computer interaction (HCI) researchers tend to focus more on rhythms of rest and activity. Both sleep and daily rhythms interact with digital media use.

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(interruptions to sleep), this paper will address the intersection of these factors and discuss implications for the wellbeing of University students and the improved design of digital media devices and systems.

1.1. Digital media use in university students

Polls of young adults in the U.S. (ages 18–29) show that 93% own cell phones and go online (Lenhart, Purcell, Smith, & Zickuhr, 2010) while 89% use social networking sites (Pew Research Internet Project, 2014). By 2013, 79% of U.S. 18–24-year-olds owned a smartphone (Smith, 2013). U.S. university students report spending an average of 12 h daily engaged with some type of media, including 9.5 h with computers, mobile devices, MP3 players and gaming devices (Alloy Media and Marketing, 2009). Another U.S. university student study found that smartphone owners used their phone "Often or Sometimes" to perform tasks other than voice calls during idle time at work or school (93%), while commuting (92%), while waiting in line (85%), when first waking in the morning (77%), and in bed before sleep at night (72%; Dean, 2010). In the hour before trying to sleep, technology use is high with reports that 67% of polled Americans use cell phones, 60% use computers or laptops, 43% use digital music devices, and 18% use video game consoles (National Sleep Foundation, 2011). Studies from other countries indicate that U.S. students' digital media use is similar to other countries. For example, among U.K. young adults, 98% use the Internet, and 90% own a smartphone. More than 70% send emails and use instant messaging and 87% visit social networking sites on their smartphones (Ofcom, 2014).

1.2. Value of sleep for university students

Galambos and colleagues showed that less sleep among first year students predicted greater negative mood while better quality sleep increased positive mood and decreased stress (2009). Poor sleep and daytime sleepiness can also negatively affect academic performance (Gomes, Tavares, & de Azevedo, 2011; Orzech, Salafsky, & Hamilton, 2011) and driving skill (Hershner & Chervin, 2014) and shorter sleep has been associated with increased incidence of common illness in adolescents(Orzech, Acebo, Seifer, Barker, & Carskadon, 2013) and adults (Cohen, Doyle, Alper, Janicki-Deverts, & Turner, 2009). Restricted sleep is associated with cardiovascular, inflammatory and metabolic consequences (Knutson & Van Cauter, 2008; Mullington, Haack, Toth, Serrador, & Meier-Ewert, 2009).

1.3. Previous work on sleep and digital media use

Experimental studies have explored the effects of music (Harmat, Takács, & Bódizs, 2008; Iwaki, Tanaka, & Hori, 2003; Lazic & Ogilvie, 2007), television (Asaoka, Fukuda, Tsutsui, & Yamazaki, 2007) and video games (Higuchi, Motohashi, Liu, Ahara, & Kaneko, 2003; Higuchi, Motohashi, Liu, & Maeda, 2005; King et al., 2013; Smyth, 2007) on sleep. Music had an equivocal or slightly positive effect on self-reported and objective measures of sleep. Reducing television viewing increased self-reported sleep time, and video game effects were mixed. Self-report sleep studies found that both computer and mobile phone use contributed to sleep disturbance (broadly defined; Thomée, Dellve, Harenstam, & Hagberg, 2010). Similar conclusions were reached by a variety of quantitative studies that assessed media use and sleep variables over short (<30 days) (Asaoka et al., 2010; Kim et al., 2010; Mesquita & Reimão, 2010) and longer durations (up to 1 year follow-up; Thomée, Eklof, Gustafsson, Nilsson, & Hagberg, 2007; Thomée, Härenstam, & Hagberg, 2011).

Two recent review papers in human–computer interaction (HCI) point to the importance of understanding digital media use related to sleep, especially in an environment of ubiquitous computing (Aliakseyeu, Du, Zwartkruis-Pelgrim, & Subramanian, 2011; Choe, Consolvo, Watson, & Kientz, 2011). HCI empirical studies do not capture sleep as a named variable, but are moving toward the intersection of digital media and sleep. For example, Golder and colleagues have examined temporal rhythms of Facebook messaging (Golder, Wilkinson, & Huberman, 2007), and Mark and colleagues have addressed stress, multitasking, and rhythms of attentional states as they relate to online activity among University students (Mark, Wang, & Niiya, 2014). A few papers in HCI/interaction design have addressed the idea of networked alarm clocks, which used conditions such as 'wake me if persons A & B are already out of bed' (Schmidt, 2006) and another that tested sharing of sleep status among previously-existing social groups (S. Kim, Kientz, Patel, & Abowd, 2008). Recently, researchers in HCI have begun to test if it is possible to track sleep and sleep-related variables using Smartphone apps (Abdullah, Matthews, Murnane, Gay, & Choudhury, 2014; Min et al., 2014), and have found that it is possible, although estimates of sleep parameters may lack precision.

When experimental studies are performed in a laboratory, researchers have more control over media exposure and often the capacity to measure sleep more precisely, but the amount of media they can test is limited, and likely does not reflect real-world University student media use. Self-report and app-based studies may collect more real-world data, but may lose precision in the measurement of both sleep and media use. One solution to this paradox is better measurement of sleep and media use in a real-world setting, which is an aim of the study reported here.

2. Theory

2.1. Effects of digital media use on sleep

Several routes may link digital media to sleep. Cain and Gradisar (2010), discussing younger adolescents, suggest three likely routes. These include 1) direct displacement of sleep by media use, for example getting involved in a computer activity and staying up late to complete it (Li et al., 2007; Oka, Suzuki, & Inoue, 2008; Zimmerman, 2008); 2) heightened physiological arousal associated with the use of digital media close to bedtime, for example playing an exciting video game, (Higuchi et al., 2005; Wuyts et al., 2012; Zimmerman, 2008); and 3) bright screens affecting physiological markers that are linked to sleep, such as melatonin (Cajochen et al., 2011; Figueiro, Wood, Plitnick, & Rea, 2011; Heath et al., 2014). It is beyond the scope of this paper to discuss these pathways in detail, but it is important to understand that there is no agreement among researchers about which pathway might represent the dominant effect of digital media on sleep.

2.2. Issues of causality

Tavernier and Willoughby (2014) address the issue of causality through their report on a 3-year longitudinal study on the relations between sleep and digital media use. They conclude that media use does not seem to cause sleep problems, but rather that students with sleep problems spend more time using digital media. They point out, however, that their study is unique and call for more research on University-aged young adults, as opposed to younger adolescents and children (Chahal, Fung, Kuhle, & Veugelers, 2013; Punamäki, Wallenius, Nygård, Saarni, & Rimpelä, 2007; Wang, Luo, Luo, Gao, & Kong, 2012).

2.3. Research question and hypothesis: the present study

In the present study, we designed a study within a larger continuing study of sleep in University students to ask the research question: How might sleep might be modified by digital media use near bedtime in a University student population? Study participants were first-year University students living on campus who had no restrictions placed on their sleep or digital media use. We investigated how participants' duration of digital media use, diversity of media use, and specific media activities affected five sleep outcomes previously reported to be associated with digital media use. Our hypothesis, given the broadly negative effect of digital media use on sleep outcomes shown in the literature, was that increased quantity of media use, increased diversity of media use, and use of specific digital media would all be associated with poorer sleep outcomes.

3. Methods

3.1. Design and participants

These data were gathered as part of a multi-year study of sleep and depression vulnerability in 1st year university students (N = 261 for 2011). Online sleep diaries querying sleep the previous night were offered daily for nine weeks, and the mean number of daily sleep diaries completed per participant was 57. In addition to completing the daily sleep diaries, participants were offered an optional digital media survey on nine occasions. Digital media surveys were only offered once each week on a Monday, Tuesday or Wednesday. Two hundred fifty-four students (48% male) completed at least one digital media survey and associated sleep diary.

3.2. Measures and procedure

3.2.1. Sleep data collection

Just before fall classes began in Fall 2011, students over the age of 18 who had completed a brief survey about sleep and mood in the Spring after their University acceptance were re-contacted and invited to participate in a second study. After providing informed consent, students received instructions via e-mail on how to log into a secure online portal to complete daily sleep diaries. Diaries were available to complete each day from early evening until the next morning from September 7, 2011, to November 15, 2011. Students received $1 per diary they completed, with bonuses for completing three and seven consecutive diaries. At the study's conclusion, students were invited to attend a debriefing session. At this session, aggregated data were shared with students, and they had an opportunity to ask questions and engage in discussion with the study's principal investigator and each other. The Lifespan Institutional Review Board approved this study. The software Illume™ (DatStat, Inc.) was used to create the surveys and collect the data online.

3.2.2. Digital media data collection

The media survey was an online, digital-media focused time diary that addressed the two hours before bedtime in 15-min retrospective blocks. As students had just completed a sleep diary, the block times were automatically generated for each student. Fig. 1 shows a sample digital media time diary, where the student reported bedtime at 1:15 AM. The first block presented started 15 min before reported bedtime (at 1 AM), the next at 12:45 AM and so on until the final block, which started two hours before bedtime at 11:15 PM.

Students selected a primary activity and, if applicable, a secondary activity from an alphabetical drop-down list for each time block. Activity choices, based on pilot data with University students, are listed in Table 1.

We are interested in what kinds of technology you used **last night** in the 2 hours before you went to sleep.

For Primary Activity, choose the technology activity that represents what you were doing for most of the 15-minute block. Fill in a Primary Activity for each time block. If you were doing another technology activity during that block, choose it as your Secondary Activity.

Example 1: Working on computer = Primary Activity = Computer work
Responding to a text = Secondary Activity = Text on phone

Example 2: Playing card game = Primary Activity = Not on list
2 minutes of Skype during block = Secondary Activity = Webcam chat/Skype

15-minute Block Start Time	Primary Activity	Secondary Activity
1:00 AM		
12:45 AM		
12:30 AM		
12:15 AM		
12:00 AM		
11:45 PM		
11:30 PM		
11:15 PM		

Fig. 1. Sample digital media survey, including instructions to participants that were shown each time they received the media survey.

3.3. Analysis

Five sleep outcomes, previously noted in sleep literature as related to digital media use were investigated and are defined below.

- Total Time in Bed (TIB, calculated by subtracting reported bedtime from reported wake time).
- Total Sleep Time (TST, calculated by subtracting the time spent awake while in bed [SOL and WASO] from TIB).
- Bedtime (BT, an exact self-reported time in hours and minutes of when participants tried to go to sleep)
- Sleep Onset Latency (SOL, how many minutes participants estimated it took them to fall asleep)
- Wake After Sleep Onset (WASO, how many minutes participants estimated they were awake during the night)

3.3.1. Analysis 1

For an initial exploration of how digital media use near bedtime might predict sleep, we used multiple regression models with each sleep variable as an outcome, predicted by blocks and diversity. Blocks described *quantity of media use* in the 2 h before bedtime (calculated from 8 primary blocks). *Diversity* looked at how many different types of media were being used and incorporated all 16

Table 1
Digital media activity choices.

Computer work	Read printed material
Email or instant messaging	Social networking site
Internet or game on phone	Surf internet
Listen to audiobook	Talk on phone
Listen to music	Text on phone
Not on List	Watch online video
Play video game	Watch TV/DVD
Read e-book	Webcam chat

blocks, primary and secondary. We also looked at the interaction between blocks and diversity. This was a mixed effects regression model where we excluded participants who reported illness or other unusual sleep-related circumstances on their sleep diary (such as crossing time zones or pulling an all-nighter, 12 participants excluded). Independent variables included number of blocks, number of different media activities (diversity), and a blocks * diversity interaction. Sex was included as a covariate.

For Analysis 1, we did not use the activity choices "not on list" (which according to a survey of study participants conducted at the time of the last digital media survey, was selected 92.5% of the time to mean they were not using technology in that interval) or "read printed material" (because it was not digital media).

3.3.2. Analysis 2

In a follow-up analysis, we explored how different types of media were related to sleep outcomes. We first calculated the number of 15-min blocks in the last hour before sleep where participants were engaged in each activity. The last hour was chosen because of its proximity to bedtime. Since students could identify a primary and secondary activity in each block, scores for each activity ranged from 0 to 8. Multiple regression analyses included sleep outcomes as dependent variables, and each of the activities listed in Table 1 as independent variables (entered simultaneously so that they were adjusted for each other), with sex as a covariate. For this analysis, we used all activity choices, as effects (or lack of effects) for commonly reported but non-digital media activities such as "read printed material" were also of interest.

4. Results

4.1. Sleep in our sample of university students

Table 2 shows mean values overall and for men and women for our variables of interest. There were no significant differences between men and women for these sleep variables.

4.2. Most common activities

Table 3 shows the seven most common primary and secondary media activities (out of 16 possible activities) averaged across nine nights and presented as percentages of participants engaging in that activity in Block 1 (2 h before their reported bedtime) and Block 8 (15 min before their reported bedtime).

Computer work and reading printed material are the most common primary activities, with listening to music and texting most common as secondary activities. Computer work, reading, listening to music (as a secondary activity), and texting increase as bedtime nears, while other reported activities decline. Although the percentages were small, we also saw an increase between Block 1 and Block 8 in engaging in a webcam chat (2%–3.2%) or talking on the phone (2.0%–2.8%) as a primary activity, and engaging in a webcam chat (1.0%–1.8%), talking on the phone (0.6%–1.5%) and watching TV or a DVD (0.7%–1.4%) as a secondary activity.

Table 2
Mean sleep values on variables of interest.

	Overall	Men	Women
TIB	7 h 21 min ± 88 min	7 h 26 min ± 86 min	7 h 17 min ± 90 min
TST	7 h 4 min ± 85 min	7 h 5 min ± 83 min	7 h 3 min ± 87 min
BT	1:13 AM ± 88 min	1:22 AM ± 87 min	1:05 AM ± 89 min
SOL	12 min ± 17 min	13 min ± 18 min	11 min ± 17 min
WASO	5 min ± 14 min	6 min ± 12 min	5 min ± 15 min

Table 3
Most common primary and secondary media activities two hours (Block 1) and 15 min (Block 8) before self-reported bedtime (percentage of participants).

	Primary activity		Secondary activity	
	Block 1	Block 8	Block 1	Block 8
Computer work	18.0	26.9	5.5	6.1
Read printed material	15.2	15.4	3.6	5.5
Surf internet	6.0	5.1	4.2	4.1
Social networking site	5.2	4.9	8.4	8.2
Email or instant message	3.6	2.3	6.5	5.2
Listen to music	3.8	3.0	16.9	22.2
Text on phone	4.0	2.4	15.5	18.1

4.3. Analysis 1

Across the nine digital media surveys, the mean number of 15-min blocks with reported media use was 4.3 blocks (S.D. 2.9, range 0–8 blocks), so students were using media, on average, for just more than one hour of the two hours before bedtime. The corresponding diversity figure was 2.5 types (S.D. 1.6, range 1–16).

The main effects of the multiple regression model for Analysis 1 are presented in Table 4. TST and BT were significantly associated with quantity and diversity of media use, while SOL and WASO were not. TIB was significantly associated with diversity of use, but not quantity of use. As the quantity of media use rose, students reported less total sleep time and later bedtimes. As the diversity of media use rose, however, students reported more total sleep time and earlier bedtimes.

4.4. Controlling for timing of digital media activities

Our initial results could have been partly explained by preferential use of diverse types of media in the early part of the two-hour window captured by our time diary. Therefore, we confined Analysis 2 to digital media use in the last hour before bedtime.

4.5. Relationship of specific digital media activities to sleep outcomes

Table 5 describes the relationship between specific activities and sleep outcomes, adjusted for sex and the other activities, for the relationships that were statistically significant ($p < 0.05$) or trend level ($p < 0.10$). A complete listing of all activities is available as a Supplementary Table (S1). Computer work *was associated* with less TST, less overall TIB, and a later bedtime, such that for each 15-min block in the last hour involving computer work, students slept about five minutes less, perhaps partially explained by going to bed five and a half minutes later. Extrapolated over the full hour, this would result in about 20 min less sleep over the course of a night. Surfing the Internet *was associated* with more *disrupted* sleep, including a longer SOL and more WASO during the night. However, Surfing the Internet was not associated with a later bedtime, and

Table 4
Main effects of multiple regression model with quantity of digital media use (BLOCKS) and diversity of digital media use included.

	Blocks B	95% CI	Diversity B	95% CI
TIB	−0.023	−0.048–0.012	0.063**	0.016–0.110
TST	−0.026*	−0.051–0.002	0.055*	0.009–0.101
BT	0.034**	0.011–0.058	−0.098**	−0.143–0.053
SOL	0.003	−0.002–0.008	0.001	−0.009–0.011
WASO	−0.004	−0.005–0.004	0.006	−0.001–0.014

*$p < 0.05$.
**$p < 0.01$.

Table 5
Activities in the last hour before sleep with significant ($p < 0.05$) or trend-level ($p < 0.10$) relationships with sleep outcomes.

Activity	B	Minutes	95% CI	P
TIB				
Computer work	−0.092	−5.52	(−0.134, −0.05)	<0.001
Listen to music	−0.046	−2.76	(−0.097, 0.005)	0.076
Read printed material	−0.051	−3.06	(−0.099, −0.003)	0.037
Text on phone	0.054	3.24	(−0.004, 0.111)	0.066
TST				
Computer work	−0.086	−5.16	(−0.127, −0.045)	<0.001
Listen to music	−0.042	−2.52	(−0.091, 0.008)	0.097
Read printed material	−0.052	−3.12	(−0.099, −0.006)	0.027
Surf the internet	−0.07	−4.20	(−0.144, 0.005)	0.068
BT				
Computer work	0.057	3.42	(0.015, 0.1)	0.008
Email or instant messaging	−0.082	−4.92	(−0.175, 0.01)	0.081
Play video game	0.258	15.48	(0.101, 0.415)	0.001
SOL				
Surf the internet	0.023	1.38	(0.007, 0.039)	0.004
WASO				
Listen to audiobook	0.071	4.26	(−0.007, 0.150)	0.075
Surf the internet	0.022	1.32	(0.010, 0.034)	<0.001

Minutes = number of minutes per block that activity reduces/increases sleep outcome. For example, computer work reduces TST by 5.16 min and pushes BT later by 3.42 min per 15-min block.

only with less TST at a trend level. Reading printed material *was associated* with *less* TST, in the context of reduced TIB, but not a significantly later bedtime. We found a relationship between bedtime and video gaming, not surprising in light of previous studies that have found links between video gaming and sleep (Smyth, 2007; Wolfe et al., 2014).

Listening to music was associated with a small reduction in TST and TIB (trend-level finding). Other trend-level findings included a relationship between texting on the phone and TIB such that texters spent three and half minutes longer in bed per 15-min block engaged in texting. Email or instant messaging was related to an earlier bedtime, such that emailers/messengers went to bed on average nearly five minutes earlier than others per 15-min block of email/messaging. Listening to audiobooks was also related to WASO in that audiobook listeners reported more wakefulness after sleep onset.

5. Discussion

5.1. Sleep and digital media use in university students

Comparing our mean sleep values to other reports of sleep in U.S. university students indicates that our participants tended to go bed a bit later than students at other institutions, on average: reporting a mean bedtime of 1:13 AM vs. 12:37 AM, but differences in the timing of data collection or the composition of the sample could explain that difference. We note that morning class start times at the University where we performed this research are no earlier than 9 to 9:30 AM. Orzech's data comes from a mostly (but not exclusively) first-year student sample at a large Western public University and was averaged across weeknights and weekends (Orzech et al., 2011). Lund and colleagues present data for weeknight and weekend bedtime for first year University students, showing mean weeknight bedtime of 12:22 AM but mean weekend bedtime of 1:58 AM (Lund et al., 2010). All of the digital media surveys in this study were administered on a Monday, Tuesday, or Wednesday night.

Comparing digital media use values to other published values is challenging, as there is no standardized way to collect media data, and only one study (of Japanese University students) had participants keep a time diary, with activity categories that were different from and broader than the ones we used in our study (Asaoka et al., 2010). For example, in that study, "Using the Internet or email on a PC" were grouped on the time diary sheet, as were "Chatting, using the telephone, and socializing." Therefore, while we agree with the general conclusion of the broader literature that use of digital media close to bedtime has a negative effect on sleep, more research collecting detailed data about digital media activities near bedtime is needed.

A key take-home message of this work is that digital media use may affect University student sleep in a negative way, and given what is known about relationships between sleep and well-being in young adults, this effect on sleep *matters*. In the short and longer term, reduced sleep, poor quality sleep, and daytime sleepiness are associated with greater negative mood (Galambos, Dalton, & Maggs, 2009), poorer academic performance (Gomes et al., 2011; Orzech et al., 2011) reduction in driving skill (Hershner & Chervin, 2014) and increased incidence of common illness (Cohen et al., 2009; Orzech et al., 2013). Although students use digital media on a regular basis, they may not be aware of the risk it poses to their health, mood, driving ability, and academic success.

5.2. Common pre-bedtime digital activities

Common activities before bedtime for this group reflect their transition to University life. As first-semester students at a well-regarded U.S. university, they are likely motivated to do well in classes by *reading and engaging in computer work*, and in fact these two activities are reported by the highest percentage of students across survey nights. However, students are simultaneously doing the social work of establishing an identity online and face-to-face with new friends as well as keeping in touch with old friends through *social media and communications channels like email, instant messages and texts* (Jacobsen & Forste, 2010). The popularity of *listening to music* may reflect two purposes – for some students, music may help them to focus on the task at hand (Calderwood, Ackerman, & Conklin, 2014), while for others it may promote relaxation and unwinding at the end of the day (Iwaki et al., 2003).

5.3. Analysis 1: findings about quantity and diversity of digital media use

Initial findings of Analysis 1 revealed more time spent using digital media associated with reduced total sleep time, although more diversity in digital media activities was associated with increased total sleep time. The first finding, related to time, supports Cain and Gradisar's (2010) suggestion of direct displacement; for students who spent more time using digital media, their sleep was reduced. The second finding suggests a divergence from the larger literature that points to a negative relationship between digital media use and sleep. To explore this further, we looked again at Cain and Gradisar's theory, focusing on differences in sleep parameters that varied by digital media activity, potentially reflecting differences in arousal/engagement associated with different activities.

5.4. Analysis 2: relationship of activities to sleep outcomes

By limiting Analysis 2, considering specific digital media activities, to the last hour before self-reported bedtime we were able to identify several activities that affected sleep outcomes, a finding that builds on to more general negative relationship between digital media and sleep by identifying particular activities associated with particular sleep variables.

We note three possible explanations for our findings of differences across activities, all of which fall under the broad umbrella of arousal/engagement identified by Cain and Gradisar (2010). The first addresses individual activities while the second and third pertain to combinations of digital media activities. First, *students may vary in their motivation to engage in and complete an activity*. Motivation has been explored in the context of media use, often as part of an explanation of why some people become addicted to Internet use while others do not (e.g., Sun, Rubin, & Haridakis, 2008). Motivation in the Internet addiction context refers to why people use the Internet, for example for information seeking, for easy access to entertainment, or for communication and social interaction. Our use of motivation, however, returns to the more basic motivational state of an organism, dependent, according to Heilman (1997) on two factors, immediate biological needs and long-term goals. Assuming the satisfaction of biological needs among University students with access to a variety of digital media leaves a focus on long-term goals – motivation, in this case, to complete tasks that help one accomplish long-term goals, such as obtaining a University degree. This type of motivation is also highlighted by Maslow in the self-esteem and self-actualization levels of his hierarchy of needs (Maslow 1943). Second, *students who are engaging in a wide variety of digital media activities close to bedtime may suffer from cognitive fatigue, which pushes them to go to bed earlier*. Several recent articles support this hypothesis, finding that high cognitive workload increased subjective fatigue and sleepiness, while producing longer SOL and less WASO than a moderate cognitive workload (Goel, Abe, Braun, & Dinges, 2014), and that fatigue is increased when participants engage in tasks with higher memory or attentional demand, especially when they are multitasking (Guastello et al., 2013). Finally, Tanaka, Ishii, and Watanabe (2014) found that performing a continuous mental fatigue-inducing task causes changes in the activation of the prefrontal cortex, and manifests as an increased beta-frequency power in this brain area as well as sleepiness.

Finally, *students engaging in a wide variety of activities may be engaging in goal-directed behavior, perhaps making a list and checking off specific tasks*. A recent study indicated that when researchers cued participants to focus on goals before completing a task, or when they sensitized participants them to avoid irrelevant stimuli, participants had more success in achieving goal-directed behavior (Hanif et al., 2012). Also related to both the goal-direction and the cognitive fatigue literature, Boksem, Meijman, and Lorist (2005) found that fatigued participants couldn't inhibit shifting their attention to irrelevant stimuli, further supporting that mental fatigue leads to a reduction in goal-directed attention. Relating goal-directed behavior back to sleep, these students may go to bed earlier because of their awareness of time and the negative effects of mental fatigue on concentration and the cost they perceive for wasting time.

5.5. Implications

These findings indicate that using digital media, especially in the hour before sleep, contributes to poorer or disrupted sleep, and that sleep effects vary by the type of digital media used. These findings are of interest to researchers who investigate sleep and those who investigate the interactions between humans and computers that make up a growing percentage of our day in the 21st century. Our findings can inform recommendations made to University students at a local (residence hall) or University wide (health promotion department) level. This increasingly supported relationship between sleep and digital media use can also inform plans for digital media devices that work to improve health. With sleep such a critical (although often overlooked) element of physical and mental health, designers could add features to devices that could alert users to best practices around turning off devices near bedtime, based on individually–entered preferences on the device itself, changing room light levels, or other indicators of approaching bedtime for an individual.

In this study, we did not ask the participants to offer explanations about why they preferred certain digital media activities, and why they performed them so close to bedtime. Results from the first author's subsequent participation in a qualitative study exploring the digital lives of young adults attending University in the UK, however, support heavy dependence on digital media, especially near sleep times. For example:

> *I will be lying in my bed and I will reach over once my alarm has gone off and just get my phone and just check and my phone has been at 100% and by the time I'm off my phone and I'm still in bed it's like 90% and I've spent 10% of my battery because I've just been lying in my bed checking my newsfeed for irrelevant information* (Charting the Digital Lifespan Participant E1, female, 1st year student)

One participant specifically mentioned using social media to check if friends are awake in the morning, which could be relevant for late-night communication as well:

> *[If I send a message on] Facebook I normally do it if I want an instant reply. So I'll look and see that they are online and then I'll Facebook them. And that way I can see if they've seen the message or not and if they are just ignoring me … sometimes I'll use Facebook [to see if they are showing up as online], to check if they are awake if it's early in the morning …* (Charting the Digital Lifespan Participant E15, male, 4th year student)

There is also the potential for digital media to interrupt sleep in the middle of the night; students being awakened at night by a digital notification should be explored further.

5.6. Limitations & future directions

A particular strength of our study is its methodological rigor in collecting long-term sleep and digital media use data from a population of University students. This rich data enables us to examine detailed interactions between digital media use and sleep outcomes, down to considering specific activities engaged in by University students near bedtime. Our data might be enhanced with a larger or more diverse sample – the students who collected data so diligently for this study may not be representative of University students as a whole. However qualitative findings from a similar age group in the UK serve to strengthen our contention that heavy media use among University students affects their daily activities, including sleep. Additional limitations include the self-report nature of these data, and the possibility that some students in the sample engaged in problematic Internet use (for example, use consistent with Internet addiction).

Further research should be carried out to collect time-specific data on digital media use in order to provide a broader base from which to draw recommendations about when to use digital media to minimize effects on sleep outcomes. Although it is beyond the scope of the current study, more detail could be collected on the specific digital media activities undertaken by students in the evening to investigate, for example, the sleep effects of filling out a nightly online sleep diary, being involved in collaborative online learning environments, or interacting in 3D virtual worlds such as Second Life (as described in (Zhang, de Pablos, & Zhu, 2012; Zhang

et al., 2014)). Further research that assesses specific psychological constructs such as motivation, fatigue, and goal-directed behavior in addition to sleep and digital media variables would also aid in explaining the differences by activity that we observed. A recent study that measured heart rate in the context of video game play before bedtime (King et al., 2013) had the surprising finding that heart rate was not significantly different across video game-playing conditions or at sleep onset, indicating that arousal as a mechanism to explain digital media's effect on sleep may also need further investigation. Finally, our design recommendations would be strengthened by design research that investigated how individuals responded to prototype devices that asked about or sensed approaching bedtime and adjusted their operation accordingly.

6. Conclusion

In these analyses, we tested the effects of quantity and diversity of media use on five sleep variables –total sleep time, time in bed, bedtime, sleep onset latency, and wake after sleep onset. While media quantity predicted later bedtime and reduced total sleep time, consistent with existing sleep-media literature, our findings for diversity of media use pointed in the opposite direction, indicating that using multiple media in the 2 h before bedtime may actually have a protective effect on sleep. The interaction between media quantity and media diversity showed that students who reported many blocks of media use increased their sleep as they increased their media use diversity, while students who reported few blocks had a less dramatic increase in TST. When we examined specific activities in the hour before bedtime, we found that activities commonly engaged in by University students had diverse relationships to sleep outcomes, with computer work, reading printed material, listening to music and surfing the Internet showing a relationship with more than one outcome, and texting on the phone, interacting with email or instant messaging, playing video games, and listening to audiobooks interacting with one of the five sleep outcomes. We proposed three possible explanations that relate to motivation, cognitive fatigue, and goal-directed behavior to explain our results. These results have implications for both University health promotion bodies helping students to sleep better, and designers seeking to improve health through digital devices that may encourage healthy sleep.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.chb.2015.08.049.

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