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The complicated impact of media use before bed on sleep: Results from a combination of objective EEG sleep measurement and media diaries

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Abstract
Media use has been linked to sleep disturbance, but the results are inconsistent. This study explores moderating conditions. A media diary study with 58 free-l iving adults measured the time spent with media before bed, the location of use, and multitasking. Electroencephalography (EEG) captured bedtime, total sleep time, and the percent of time spent in deep (Stage N3), and rapid eye movement (REM) sleep. Media use in the hour before sleep onset was associated with an earlier bedtime. If the before bed use did not involve multitasking and was conducted in bed, that use was also associated with more total sleep time. Media use duration was positively associated with (later) bedtime and negatively associated with total sleep time. Sleep quality, operationalised as the percent of total sleep time spent in N3 and REM sleep, was unaffected by media use before bed. Bedtime media use might not be as detrimental for sleep as some previous research has shown. Important contextual variables moderate the relationship, such as location, multitasking, and session length.

Keywords: bedtime, electroencephalography, multitasking, screens, sleep onset

Introduction

Insufficient and poor-quality sleep are associated with negative health outcomes, such as overweight and obesity (Vargas, Flores, & Robles, 2014), worsening cognitive function (Beebe, Field, Millller, Miller, & Leblond, 2017; Kronholm et al., 2009), higher mortality rates (Gallicchio & Kalesan, 2009), and cardiovascular diseases (Clark et al., 2016). Poorer sleep quality is also associated bidirectionally with mental health outcomes such as depression and anxiety (Fang, Tu, Sheng, & Shao, 2019; Tavernier & Willoughby, 2014), as well as reduced life satisfaction (Lemola, Ledermann, & Friedman, 2013). Despite research showing the importance of sufficient, good-quality sleep, problematic patterns such as insufficient sleep time have increased in the USA (Sheehan, Frochen, Walsemann, & Ailshire, 2019).

One factor that contributes to sleep problems is media use (Chang, Aeschbach, Duffy, & Czeisler, 2015; King, Delfabbro, Zwaans, & Kaptsis, 2014; Suganuma et al., 2007). Media use has been found to be negatively related to perceived sleep quality (Suganuma et al., 2007) and observed sleep (Chang et al., 2015), and positively related to delayed bedtime (King et al., 2014). Of particular concern has been the use of media shortly before sleep onset. For example, one study demonstrated that media use in the 30 min prior to sleep is associated with sleep disturbances (Levenson, Shensa, Sidani, Colditz, & Primack, 2017). Other research has found similar effects when looking at media use up to 2 hours before sleep onset (Custers & Van den Bulck, 2012; Exelmans & Van den Bulck, 2017a; Hale & Guan, 2015).

Multiple reasons have been proposed as to why media can have a negative effect on sleep (Chang et al., 2015; Custers & Van den Bulck,

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2012; Exelmans & Van den Bulck, 2018; Repa, Rodriguez, & Garland, 2018; Van den Bulck, 2004). Some research suggests that screen light wavelength is to blame (Repa et al., 2018). Other research has pointed to sleep displacement, where the time that would have been spent sleeping is instead spent using media, leading to shorter sleep duration (Exelmans & Van den Bulck, 2018; Van den Bulck, 2004). Bedtime procrastination, in which individuals push back both sleep onset and rise time to accommodate media use, also leads to decreased sleep quality (Custers & Van den Bulck, 2012). Media use may also increase cognitive arousal, which impacts sleep quality, perceived fatigue, and insomnia frequency (Exelmans & Van den Bulck, 2017b).

Yet, some evidence suggests that some media use before bed might not have a strong negative effect (Jones et al., 2017). A recent review (Hale & Guan, 2015) concluded there is equivocality in terms of the effect of media on sleep. One possibility is that not all media use is the same – the type and context of the media use matters. For example, according to the *media use for recovery* hypothesis (Reinecke, Hartmann, & Eden, 2014; Reinecke, Klatt, & Krämer, 2011), individuals may use entertainment media for need satisfaction which leads to greater well-being and overall recovery from daily stressors. For example, one study found that participants who were given a stressful task were more likely to feel recovered and to perform well on a subsequent cognitive task after they had engaged with enjoyable media (Reinecke et al., 2011). Given the relationship between sleep quality and psychological strain (Van Laethem et al., 2015), the recovery hypothesis could suggest that certain types of media use could be beneficial for sleep quality.

A recent review of the literature regarding the effects of media on sleep suggests that many conclusions are limited by three main issues: unreliable measurement of both sleep and media use, reliance on panel data, and the lack of attention to specific characteristics of media use and content (Hale & Guan, 2015). The present study attempts to address several of these issues. Specifically, the present study employs a media diary coupled with objective sleep measurement using electroencephalography (EEG). Much of the research relating to sleep quality and media use has relied on retrospective and subjective self-reports from participants. The present study pairs media use diaries in a given day with sleep measures that night, allowing for time-ordered relationships to be examined between screen media use and sleep. Measurement specificity is also enhanced by objective EEG rather than relying by on participant self-report.

Finally, we examine the characteristics of media use, including whether the use occurred in the hour before bed, as well as what that use consisted of: whether participants engaged in multitasking, whether the media use occurred in bed or elsewhere, and the total length of the media session. Media use in the hour before bed was selected due to the focus it has received in other work. Multitasking was included based on past work examining the role of media multitasking on sleep (van der Schuur, Baumgartner, Sumter, & Valkenburg, 2018). Whether the use before bed occurred in bed was included due to a multitude of studies suggesting that the existence of a television in the bedroom is detrimental to sleep quality (Brockmann et al., 2016). In addition, the total minutes spent using media before bed was included due to previous research suggesting that binge use, which involves long media sessions, was associated with reduced sleep quality but regular non-binge use was not (Exelmans & Van den Bulck, 2017b). In this study, we focus on traditional, or legacy, media use as previous research has suggested that such media (e.g., television, radio, films, video games, music and music videos) may not be as problematic for sleep as once assumed (Hale & Guan, 2015; Jones et al., 2017). Legacy media are media that can be considered "mass" – one source to many audience members. These are contrasted with social media, which are many sources to many audience members, as well as interpersonal communication (e.g., text messaging) which is one source to one audience member. The results of the present study will therefore address gaps in the literature on media use and sleep (Hale & Guan, 2015) and inform future research on their association.

2 | METHODS

2.1 | Participants

Participants were 58 adults living in mid-Michigan who were part of a community research pool associated with Michigan State University. The average age was 26.14 years (range 19–66 years), 44 (75.86%) were female, 45 (77.59%) identified as White or Caucasian, 5 (8.62%) as Black or African American, 3 (5.17%) as Asian or Pacific Islander, 2 (3.45%) as multiracial, 1 (1.72%) as Hispanic or Latino, 1 (1.72%) as Arab or Middle Eastern, and 1 (1.72%) as Native American or Alaskan Native. Participants were paid $5 for the initial survey and $100 for the 3-day sleep and media diary study.

2.2 | Procedure

2.2.1 | Initial survey and recruitment

This study involved two parts: an initial recruitment survey followed by a 3-day study during which the participants completed media diaries and wore EEG-based sleep monitors to bed at home. A total of 473 participants (M_{age} = 28.56 years, 76.32% female) from a community research pool participated in the recruitment survey. In order to ensure appropriate variability in television use a coarsened exact matching procedure (Iacus, King, & Porro, 2012) was run to identify high and low media users. Coarsened exact matching selects pairs of participants that are matched to one another on specified dimensions. In the case of the present study, the pairs were selected to match based on sex (male or female), age (above or below the median of 25 years), racial identity (White/Caucasian vs. other[1]), BMI (under/

[1]It is not our intention to imply that all non-White racial and ethnic groups have similar sleep topography or media use. It was the limitation of the initial sample that did not allow for matching based on more fine-grained identity data, yet to ignore race and ethnicity in matching would also be problematic. The compromise solution was to coarsen racial identity as White and other.

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normal weight vs. overweight/obese), sleep aid use, dietary restraint (low, middle, high)[2], days of vigorous activity per week (zero vs. one or more), and overall media use (low, less than 15 h per week; middle, 15–23.5 h per week; high, 24 h or more per week). This resulted in the selection of 41 matched pairs of 82 participants. Recruiters contacted individuals up to three times to recruit them for the full study. Of the 82 originally selected by the coarsened matching procedure, 58 participated in the 3-day study.[3]

2.2.2 | Three-day diary study

The diary study had three phases: (1) an initial session (always a Monday) where each participant was trained how to fill out the media diary and to use the sleep monitor, (2) a 3-day period (always a Tuesday, Wednesday, Thursday) in which participants kept diaries of their media use and used the sleep monitor to record their sleep patterns, and (3) an end-session (always a Friday), which consisted of reviewing the media diary with participants to check for completeness, and then viewing the sleep machine data with participants. Previous research has found 3 days to be a reliable number for sleep measurement (Aili, Åström-Paulsson, Stoetzer, Svartengren, & Hillert, 2017), and food-diary method studies have found 3 days to be the optimal length for reporting accuracy (Crawford, Obarzanek, Morrison, & Sabry, 1994; Yang et al., 2010).

During the initial session, the participants were directed to record their media use for the next 3 days using a provided diary packet. They were instructed to carry their diary with them for the remainder of the week and to record all media they consumed for entertainment or information purposes (e.g., watching movies, television, or YouTube videos, browsing the Internet, listening to music, etc.). Specifically, the participants were asked to report the name of the programme/media item, at what time the consumption occurred, and for how long it lasted. Participants were told to exclude social media use (i.e., any media in which their primary purpose was to interact with others), as the focus of the present study was on traditional media (i.e., media used for entertainment or informational purposes). As a result, our media variable included TV shows, video games, music, etc. There were many reasons for the exclusion of social media usage, including the sporadic nature of social media use and previous findings suggesting that self-reported social media use is only modestly related to actual use (Parry et al., 2021). Next, the participants were instructed how to operate the sleep monitor (Zmachine, described below). A research assistant showed participants the device, how to wear it, and explained the device's instruction manual while demonstrating the instructions on the machine. The participants were told to wear the monitor for 3 nights, and to discontinue if it disrupted their normal sleep. Participants were instructed to put the monitor on at least 10 min before they got into bed, and that they should act normally while wearing it (e.g., reading books, watching TV, going to the bathroom). The third phase of the study always took place on the immediate Friday, and consisted of reviewing the participant's data, showing them graphs of their sleep patterns for the previous 3 days with feedback on their sleep habits, and compensating them for their time. Training protocols for the media diaries and Zmachines are available on OSF: https://osf.io/26w4z/?view_only=9a9b5a25550f4141ad4101a7a4d23482

2.3 | Measures

2.3.1 | Media diary information

There were a total of 174 days of diary across 58 participants. Some percentages do not sum to 100 due to missing data. The numbers will usually sum above 58 due to multiple observations per participant. Incidences of use are reported below as the number of incidences (which could be more than one night per participant) as well as the number of participants (which would mean the participant engaged in that activity at least one night).

Media use before bed

Media use before bed was defined as an entry of a media event in the media diary within 1 hour of sleep onset as measured by the Zmachine. A total of 42 days of media use in the hour before bed were reported by 24 participants (24.14% of all media diary days recorded, from 41.38% of participants).

Minutes spent in media session that occurred before bed

The participants reported time spent with a given media event by indicating the start time and the end time. The total minutes spent with the media event were calculated by taking the difference. The minutes spent in media events that specifically overlapped with the hour before sleep onset were included in the analysis (n_{events} = 41, 23.56%, $n_{participants}$ = 24, 41.38%, M = 90.98 min, SD = 111.94).

Location

The participants recorded where they were located whenever using media in their media diaries. One location option was "in bed". When the participants reported using media in bed, and that media event was coded as occurring within an hour of sleep onset, it was considered using "in bed, before bed" (n_{events} = 17, 9.77%, $n_{participants}$ = 11, 18.97%). When the participants reported using media within an hour of sleep onset that was not located in bed, it was considered using "not in bed, before bed" (n_{events} = 25, 14.37%, $n_{participants}$ = 17, 29.31%). When the participants reported media use outside of the window of

[2]Dietary data was relevant for an analysis with different measures regarding media use and nutrition, which has been published as [citation blinded for review].

[3]We created a variable in the initial survey dataset that grouped participants into one of three categories: those who (1) were not selected for the diary study (n = 405), (2) were selected but did not participate (n = 24), or (3) were selected and participated (n = 58). Using ANOVA (continuous) and Chi-square (dichotomous/multinomial), there were no significant differences between these three groups on any relevant variables: age, sex, BMI, amount of media use, Pittsburgh Sleep Quality Index, sedentary behaviour, and exercise behaviour. Therefore, we do not believe there were any systematic differences by inclusion in the diary subsample.

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an hour before sleep onset, regardless of location, it was coded as "not before bed" (n_{events} = 117, 67.24%, $n_{participants}$ = 49, 94.23%).

Multitasking during media use

The participants reported whether they were engaging in any other activity while they used media, which was the definition of multitasking for this study. If a media event occurred within an hour of sleep onset and the participant reported multitasking during that media event, it was coded as "multitasking, before bed" (n_{events} = 17, 9.77%, $n_{participants}$ = 10, 17.24%). If a media event occurred within an hour of sleep onset and the participant did not report multitasking during that media event, it was coded as "not multitasking, before bed" (n_{events} = 25, 14.37%, $n_{participants}$ = 17, 29.31%). If the event was reported as occurring outside the window of an hour before sleep onset it was coded as "not before bed" (n_{events} = 117, 67.24%, $n_{participants}$ = 49, 94.23%).

2.3.2 | EEG sleep measurements

The Zmachine (General Sleep) is a portable, single channel (A1–A2) electroencephalograph (EEG). The device uses an automated scoring algorithm to categorise sleep into different stages, effectively eliminating human scorer subjectivity. Sleep data collected from the Zmachine for this study included: total sleep time (TST), deep (N3) sleep, and REM sleep. The Zmachine has been compared against polysomnography (PSG), the gold standard for sleep measurement, and was found to have a substantial agreement in identifying the sleep measures used in this study (Cohen's Kappa = 0.72 for all; Wang, Loparo, Kelly, & Kaplan, 2015). The major advantages of the Zmachine compared with PSG are that the participants can use the device at home, sleep in their own bed, and do not require assistance to place the sensors. Central tendency information in the following sections is provided across all the 174 sleep days available in the dataset.

Zmachine trouble

The participants were able to report if they had issues with the Zmachines, which included issues such as disconnecting during sleep, skin reactions to the adhesive gel, and inability to sleep due to discomfort. Twenty-seven participants (46.55%) reported no issues, 13 participants (22.41%) reported an issue on 1 night, 9 participants (15.52%) reported an issue on 2 nights, and 9 participants (15.52%) reported issues on all 3 nights. Trouble with the Zmachine on each night was included as a dichotomous covariate in analyses[4].

Bedtime/sleep onset

The Zmachine reported the clock time at which the participant fell asleep. On each night the sleep time was coded with sleep onset between 9:31 pm and 10:00 pm local time as 0, between 10:01 pm and 10:30 pm as 1, between 10:31 pm and 11:00 pm as 2, and so on in half hour increments (range 0–16, *M* = 6.11, SD = 2.95).

Total sleep time

The total minutes spent asleep were recorded, from sleep onset to sustained waking (*M* = 349.06, SD = 113.23).

Time spent in deep (Stage N3) sleep and REM sleep

Deep sleep was defined as Stage 3 non-REM sleep, and was measured in minutes (*M* = 87.14, SD = 32.35). The time spent in REM sleep was recorded in minutes (*M* = 90.57, SD = 42.28). Previous literature has looked at the percent of sleep time spent in N3 sleep and/or REM sleep to explain sleep quality (Friese, Diaz-Arrastia, McBride, Frankel, & Gentilello, 2007; Naismith, Winter, Gotsopoulos, Hickie, & Cistulli, 2004). Both variables are still commonly used as a criterion for quality (André et al., 2020; Miller et al., 2020). Therefore, the current study added the two measures together and divided by the total number of sleep minutes to obtain a ratio measure for the percent of total sleep time attributable to N3 and REM sleep (*M* = 0.51, SD = 0.11). This method of looking at the percent of time spent in N3 and REM as a single cohesive unit has been used previously and has shown a significant effect (Szczygiel, Cho, & Tucker, 2018).

2.4 | Statistical analysis

The unit of analysis was a day (*n* = 174), with 3 days of data for each participant (*n* = 58). Media use variables were collected for each of the 3 days preceding 3 nights of sleep data, such that media use on Day 1 preceded Night 1 sleep. Data were analysed in Stata 14.0 using path analysis and OLS regression. Standard errors were clustered to account for multiple observations per participant. Models included all sleep outcome variables as endogenous variables with covarying error terms to account for the correlations between them. Participant age, sex (female = 0, male = 1), BMI, sleep aid use (*n* = 4), and Zmachine technical issues were included as covariates, and treated as correlated exogenous variables. A separate model was run for each of the focal media predictors due to high multicollinearity (*M* VIF = 6.97). Correlations between all variables in the model can be found in Table 1, and full statistical results from regression analyses can be found in Table 2.

3 | RESULTS

Over 40% of participants reported using media in the hour before bed on at least 1 night. Overall, there was a complex association between media use before bed and sleep. In general, media use before bed was associated with an earlier bedtime, and also with more sleep, when the use was not concurrent with multitasking and when it occurred in bed and was of shorter duration. However, this effect was diminished by multitasking or use outside of the bed and was negated the longer the media session lasted. More specifically, media use in the hour before

[4]Results are largely unaffected by controlling for Zmachine trouble compared with removing data from nights where trouble occurred.

TABLE 1 Pairwise Pearson correlations (for continuous/continuous pairs), polychoric correlations (for dichotomous/continuous pairs), and tetrachoric correlations (for dichotomous/dichotomous pairs) between demographic variables, media variables, and sleep variables

	Age	Sex	BMI	Sleep aids[a]	Zmachine trouble	Clock time	Total sleep time	% N3 and REM	Before bed[b]	Multi-tasking before bed	Media in bed	Before bed minutes
Age	-											
Sex	−0.04	-										
BMI	0.54***	0.01	-									
Sleep aids	0.08	1.00[c]	0.35**	-								
Z-Machine trouble	−0.18	0.10	−0.06	0.00	-							
Clock time	−0.04	0.10	0.03	−0.30	0.12	-						
Total sleep time	−0.16	0.00	−0.18	0.21	−0.57	−0.36***	-					
Percent N3 and REM	−0.10	−0.26	−0.08	0.05	0.09	0.15	−0.19*	-				
Before bed	−0.10	−0.10	−0.17	−0.33	0.13	−0.50	0.19	0.12	-			
Multitasking before bed	−0.66	0.28	−0.26	−1.00	0.08	0.00	−0.31	0.22	-	-		
Media in bed	−0.01	−0.14	0.00	1.00	0.24	−0.55	0.45	0.22	-	−0.59	-	
Before bed minutes	−0.07	0.08	−0.15	−0.45	−0.03	0.50**	−0.54**	0.16	-	0.67	−0.73	-

Note: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$; however, Stata's polychoric command does not provide p-values.

[a]Only four participants reported using sleep aids; due to missing data in the media diaries for these individuals there is only one individual using sleep aids included in the tetrachoric correlations with the media items (hence, the perfect correlations).

[b]Media use before bed is perfectly related to the multitasking, in bed, and minutes measures because use before bed is a necessary requirement for those measures.

[c]All persons reporting the use of sleep aids were female.

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TABLE 2 Results of generalised structural equation (path) models

	Clock time at sleep onset		Total sleep (minutes)		% N3 and REM Sleep	
	b	95% CI	*b*	95% CI	*b*	95% CI
Model 1						
Age	−0.03	−0.09, 0.03	−0.08	−1.72, 1.55	−0.00	−0.00, 0.00
Sex	0.10	−1.39, 1.59	22.72	−14.26, 59.69	−0.04	−0.08, 0.01
BMI	0.03	−0.06, 0.13	−2.14	−4.68, 0.41	−0.00	−0.00, 0.00
Sleep aid use	**−2.43**	**−3.53, −1.32**	52.85	−29.64, 135.33	−0.00	−0.06, 0.06
Zmachine trouble	0.67	−0.55, 1.89	**−101.81**	**−144.03, −59.60**	0.03	−0.01, 0.06
Before bed	**−2.21**	**−3.47, −0.95**	21.29	−23.92, 66.50	0.01	−0.02, 0.04
Model 2						
Age	−0.03	−0.09, 0.03	−0.45	−2.11, 1.21	−0.00	−0.00, 0.00
Sex	0.12	−1.39, 1.62	26.72	−8.63, 62.07	−0.04	−0.08, 0.01
BMI	0.03	−0.06, 0.13	−2.16	−4.58, 0.25	−0.00	−0.00, 0.00
Sleep aid use	**−2.43**	**−3.53, −1.33**	50.58	−30.15, 131.31	−0.00	−0.05, 0.04
Zmachine trouble	0.68	−0.54, 1.90	**−101.36**	**−140.24, −62.47**	0.03	−0.03, 0.04
Multitasking[a]						
Before bed, no multitask	**−2.14**	**−3.28, −1.01**	**62.44**	**26.83, 98.04**	0.01	−0.03, 0.04
Before bed, multitask	**−2.32**	**−4.26, −0.39**	−40.69	−118.86, 37.49	0.01	−0.03, 0.05
Model 3						
Age	−0.03	−0.09, 0.02	−0.11	−1.60, 1.39	−0.00	−0.00, 0.00
Sex	0.06	−1.43, 1.56	24.06	−14.58, 62.70	−0.03	−0.08, 0.01
BMI	0.03	−0.06, 0.13	−2.09	−4.51, 0.33	−0.00	−0.00, 0.00
Sleep aid use	**−2.33**	**−3.50, −1.16**	49.11	−27.56, 125.78	−0.01	−0.05, 0.04
Zmachine trouble	0.75	−0.49, 1.99	**−104.95**	**−145.99, −63.92**	0.02	−0.01, 0.05
Location[a]						
Before bed, not in bed	**−1.49**	**−2.71, −0.28**	−6.67	−67.78, 54.45	−0.01	−0.05, 0.02
Before bed, in bed	**−3.26**	**−4.96, −1.56**	**62.74**	**20.14, 105.33**	0.04	−0.00, 0.08
Model 4						
Age	−0.03	−0.12, 0.07	0.54	−2.42, 3.50	**−0.00**	**−0.00, −0.00**
Sex	**1.82**	**0.34, 3.30**	31.95	−70.59, 134.48	−0.02	−0.08, 0.05
BMI	0.10	−0.08, 0.27	−1.83	−9.02, 5.35	−0.00	−0.01, 0.00
Sleep aid use	−3.28	−6.64, 0.09	139.72	−0.03, 279.47	−0.05	−0.14, 0.05
Zmachine trouble	0.51	−0.91, 1.94	**−114.65**	**−220.45, −8.84**	0.01	−0.00, 0.00
Total minutes before bed	**0.01**	**0.00, 0.01**	**−0.36**	**−0.58, −0.15**	−0.00	−0.00, 0.00

Note: Results for covariates were obtained with a model without any focal predictors. Each focal predictor (before bed, multi-tasking, in bed, and media minutes) was included in a separate model due to multicollinearity. Significant coefficients ($p < 0.05$) are bolded for ease of interpretation.

[a]Comparison group = no media use before bed.

sleep onset was associated overall with an earlier bedtime, but with no difference in total sleep time or the percent of time spent in N3 and REM sleep. Media use in the hour before bed was associated with an earlier bedtime regardless of multitasking. However, only media use without multitasking in the hour before bed was associated with increased total sleep time, with no effect on the percent of time spent in N3 and REM sleep. It also did not matter for earlier bedtime whether the media use in the hour before bed was conducted in bed or not in bed, as both were significantly associated with an earlier bedtime. However, only use in the hour before sleep onset that occurred in the bed was significantly associated with increased total sleep time. Finally, there was also an association between media session-length before bed and both bedtime and total sleep time, such that longer media sessions before bed were associated with later bedtimes and less total sleep time. There was no association of media session length with percent of time spent in N3 and REM sleep.

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4 | DISCUSSION

Previous research has demonstrated that media use before bedtime can be problematic for sleep (Exelmans & Van den Bulck, 2017a; Hale & Guan, 2015). Yet a growing body of research also indicates that the relationship between media use and problematic sleep may be more complicated (Jones et al., 2017). Researchers have called for more detailed and non-correlational methods to be employed in research investigating the impact of media on sleep (Hale & Guan, 2015). The present study used a media diary methodology to gain a clearer understanding of how people use media before sleep onset, and the relationships with media use and subsequent same day sleep. Our study provided some contextual variables about media use in the 1 hour window before sleep onset that were differentially associated with sleep variables as measured by EEG. Overall, the use of media in the hour before sleep onset was associated with an earlier bedtime and with increased total sleep time. However, this effect was diminished when the media use was accompanied by multitasking and when the use occurred in a location other than in bed. The improvement in sleep associated with bedtime media use was also negated by the length of the media session; the longer the before-bed media session in minutes, the less sleep the participants had. However, sleep quality operationalised as the percent of sleep spent in N3 and REM sleep was not related to media use before bed. It should be noted that the effect sizes for these relationships were overall relatively small; however, media effects are often small but build up over time, in a process outlined by the "drip hypothesis" (Bahk, 2020; Lang & Ewoldsen, 2010). Additionally, very small coefficients, such as those for the length of the media session, can be extrapolated to more meaningful interpretations. The coefficient for predicting total sleep time can be interpreted as each additional minute in the media session before bed was associated with 20 fewer seconds of sleep. While this likely seems miniscule, it can be extrapolated that a typical binge viewing session of 2 hours would be associated with 40 fewer minutes of sleep.

These results provide more nuance to the relationship between bedtime media use and sleep, heeding the call to include more objective and reliable measurement of sleep and media use, as well as to consider potentially important contextual variables. One possible explanation for the relative difference in our findings from prior work is the use of objective measures. In past research, self-reported time spent in bed, but not necessarily sleeping, is often used as a proxy for sleep instead of objective sleep measures (Van den Bulck, 2004). However, self-reported sleep can be unreliable, and time in bed does not always account for non-sleep behaviours such as talking, reading, or attempting but failing to sleep (Reed & Sacco, 2016).

4.1 | Practical implications

The results of the present study suggest that it may be acceptable, and beneficial, to use some forms of media before bed, under certain conditions. Specifically, the media use should involve no multitasking with simultaneous activities and should be kept relatively short. Being in bed during use also seems to help rather than hinder sleep, which is in contrast with current sleep hygiene recommendations (Mastin, Bryson, & Corwyn, 2006) and contrary to other studies that find having a television in the bedroom is detrimental for sleep (Brockmann et al., 2016). However, it should be noted that most of the research on bedroom television has been conducted in children, and the present study recruited adult participants. More research is needed to better understand whether this finding in our adult population is due to life stage, development, or another reason.

The results also offer further insight into the mechanisms for how media use might influence adult sleep. The fact that bedtime and total sleep time were associated with media use, but not the percent of sleep spent in N3 and REM sleep, indicates support for sleep displacement (Exelmans & Van den Bulck, 2018; Van den Bulck, 2004) and sleep procrastination (Custers & Van den Bulck, 2012) as aspects to focus on in future research. It may be possible to create interventions that allow for media use before bed that do not lead to sleep displacement or procrastination. Future research should look further at these mechanisms for the relationship between media use and sleep.

4.2 | Strengths, limitations, and future research

The present study employed many factors that have been called for to improve media and sleep research. However, there are some aspects that limit the ability to draw conclusions. First, the 3 days of the diary study were purposefully kept tightly controlled, with all diary and EEG measurement on Tuesday, Wednesday, and Thursday of a given week. This was to ensure that day of the week did not influence the results. However, it is likely that both media use and sleep behaviours would be different on weekends versus weekdays (Roepke & Duffy, 2010), and future research should replicate these results on other days and with other lengths of measurement.

Second, we did not ask participants what media device they were using. Therefore, participants could have been watching on a television, a laptop or desktop computer, a tablet, or a smartphone. Previous research has found an effect of device on sleep, such that more interactive devices have a stronger effect on sleep than more passive devices (Gradisar et al., 2013). However, that study did not differentiate what kind of content was being consumed on those devices. We have no empirical basis to expect that watching the same show on a television compared with a smartphone would differentially impact sleep; however, this remains an open question.

Our exclusion of social media in the present study was deliberate for a few reasons. First was that much of the conversation on the equivocal nature of the relationship between media use and sleep has focussed on traditional media use such as television, while the relationship for social media use is less contentious in the conclusion that it is detrimental for sleep (Exelmans & Van den

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Bulck, 2017b; Hale & Guan, 2015). That said, there was a recent experiment conducted in a sleep laboratory that found no detrimental effect of social media use before bed on sleep quality (Combertaldi, Ort, Cordi, Fahr, & Rasch, 2021). Therefore, it is possible that the influence of social media use on sleep is more under question than previously thought when the data for the present study were collected. Second, social media use is different from traditional media use in that much of it is not completed in large blocks of time but instead in small snippets throughout the day – one poll found that young adults check social media up to 20 times per day (London, 2012). This behaviour is often habitual and done spontaneously without much awareness (e.g., picking up the phone and opening the app for Facebook without consciously intending to; Du, van Koningsbruggen, & Kerkhof, 2020). Given the way social media use occurs in many small, automatic snippets, it would be burdensome on participants to record every instance throughout the day, not to mention less accurate due to the automaticity of the behaviour (see Parry et al., 2021). Notably, this study was conducted in 2018 before (1) the widespread adoption of apps such as TikTok, which have resulted in longer-periods of social media use, and (2) smartphones' ability to unobtrusively record screen-time spent with apps.

However, by not including social media, we may have missed concomitant media use involving, e.g., television and phone use at the same time. Such behaviours would have been captured by the multitasking measure, but we cannot differentiate between multitasking with social media and multitasking with other behaviours, such as doing the dishes or eating a snack. Even if that is the case, however, it does not change the fact that bedtime traditional media use was associated with better sleep quality, regardless of alternative activity. It also does not impact the conclusions we can draw from the contextual variables that diminished or enhanced this relationship, such as location and session length. Nevertheless, examining the association between social media use and sleep quality is an area ripe for future study, especially given advancements in smartphone technology that allow researchers the ability to objectively measure social media use on participants' phones, without the need for self-report.

5 | CONCLUSION

The results of the present study were based on objective measures of sleep and on real-time media use records rather than on retrospective reports, as well as the inclusion of contextual factors that influenced the strength and directionality of the relationship between media use in the hour before bed and sleep outcomes. The findings present a complex picture, where media use before bed appears to be less detrimental for sleep than suggested by other research – as long as that use is not accompanied by multitasking, is conducted in bed, and the session is short. This has implications for research on sleep and traditional media use and points to the likelihood that there is more nuance to the issue of media use before bed than previously assumed.

AUTHOR CONTRIBUTIONS

ME, AE, and RT conceived of the study design. LH and CY conducted the study. ME and EU conducted the data analysis and wrote the initial manuscript draft. All authors provided feedback on the final manuscript.

DATA AVAILABILITY STATEMENT

Data are available upon request from the first author.

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