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Associations between bedtime media use and sleep outcomes in an adult population-based cohort

Stephanie Schrempft [a,*], Hélène Baysson [a,b], Ambra Chessa [a], Elsa Lorthe [a,c], María-Eugenia Zaballa [a], Silvia Stringhini [a,d,e], Idris Guessous [b,f,1], Mayssam Nehme [a,f,1], on behalf of the Specchio study group[2]

[a] Division of Primary Care Medicine, Unit of Population Epidemiology, Geneva University Hospitals, Geneva, Switzerland
[b] Department of Health and Community Medicine, Faculty of Medicine, University of Geneva, Geneva, Switzerland
[c] Université Paris Cité, Inserm, INRAE, Centre for Research in Epidemiology and Statistics Paris (CRESS), Paris, France
[d] University Centre for General Medicine and Public Health, University of Lausanne, Lausanne, Switzerland
[e] School of Population and Public Health, Faculty of Medicine, University of British Columbia, Vancouver, Canada
[f] Division of Primary Care Medicine, Geneva University Hospitals, Geneva, Switzerland

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ABSTRACT

Objective: To further examine the relationship between bedtime media use and sleep in adults by taking relevant covariates into account and testing hypothesised mediating and moderating pathways.
Methods: Bedtime media use and sleep outcomes were examined by questionnaire in 4188 adults (59 % women, aged 19–94 years) from the Specchio cohort based in Geneva, Switzerland. We tested associations between bedtime media use and sleep (bedtimes, rise times, sleep latency, sleep duration, sleep quality, insomnia, and daytime sleepiness), adjusting for prior sleep, mental health, and health behaviours; whether bedtime media use mediates associations between individual susceptibility factors (age, chronotype, and mental health) and sleep; and whether individual susceptibility factors moderate associations between bedtime media use and sleep.
Results: Often using a screen in the 30 minutes before going to sleep at night was associated with a late bedtime (≥midnight; OR [95 % CI] = 1.90 [1.44,2.51], $p < 0.001$), a short sleep duration (<7 h; 1.21 [1.01,1.46], $p < 0.05$), and excessive daytime sleepiness (Epworth score >9; 1.47 [1.25,1.74], $p < 0.001$), adjusting for all covariates. Bedtime media use partly mediated the association between younger age and an evening chronotype and these sleep outcomes. Mental health moderated the association between bedtime media use and sleep quality/insomnia, such that the former was only associated with poorer sleep quality/insomnia among individuals with better mental health.
Conclusions: Frequent bedtime media use was associated with various sleep outcomes, independently of relevant covariates. Limiting the use of screens at bedtime is important to promote sleep among adults. Individuals with poorer mental health likely require additional support to improve their sleep quality.

1. Introduction

Complaints of disturbed or poor quality sleep are widespread in the general population [1] and have health, social, and economic consequences [2]. Poor sleep can impair cognitive and daytime performance [3], increases the risk of accidents [4], and is associated with various physical and mental health problems [5]. Over time, poor sleep increases the risk of a shorter life span [6]. Understanding how modifiable behaviours impact sleep is therefore important to inform the development of sleep promotion strategies, which can empower individuals, and ultimately improve population health and reduce costs to society.

The advent of internet-enabled portable small screen devices, such as smartphones, has had a huge impact on people's use of digital media. People now spend most of their leisure time using digital media [7,8], including during the period before going to sleep. Use of screen media, particularly before bedtime or after getting in bed, has been linked to less total sleep time, poor sleep quality, and daytime sleepiness [9–12].

* Corresponding author.
E-mail address: stephanie.schrempft@hug.ch (S. Schrempft).
[1] Joint last author.
[2] Listed in the acknowledgements.

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Abbreviations

DSMM = Differential Susceptibility to Media Model
ESS = Epworth Sleepiness Scale
ISI = Insomnia Severity Index
PHQ-4 = 4-item Patient Health Questionnaire
PSQI = Pittsburgh Sleep Quality Index
rMEQ = reduced Morningness-Eveningness Questionnaire
RMSEA = root mean square error of approximation
TLI = Tucker Lewis Index

Systematic reviews report that most, but not all [13–15], published studies show a significant adverse association between digital media use and at least one of the measured sleep outcomes [9–12]. Potential mechanisms linking bedtime media use and sleep include sleep displacement (bedtime media use can displace sleep time through delayed bedtime) [16], heightened mental, emotional, or physiological arousal, which can make it difficult to fall asleep [17], and exposure to bright light from screens, which can delay the body's melatonin production and adversely impact sleep [18].

Much of the research examining the relationship between bedtime media use and sleep has been conducted among children and adolescents [9–12]. The existing research in adults has reported associations between bedtime media use and various aspects of sleep including later bedtimes, shorter sleep duration, poorer sleep quality, and insomnia symptoms [19–23], but these studies were cross-sectional and took into account a limited range of covariates. The reported associations could be explained by users turning to media to pass the time when they are having difficulty sleeping, or by individual differences that draw some people to media use, or by other health behaviours that overlap with bedtime media use and sleep, such as total time spent using digital media, and physical inactivity [24]. Indeed, findings from several studies suggest that high levels of total media use may be a symptom rather than a cause of sleep problems [25,26], highlighting the importance of taking into account prior sleep and mental health.

According to the differential susceptibility to media model (DSMM) [27], media use is predicted by individual difference variables, such as temperament, mood, and developmental level. In turn, media use can provide the causal connection between these individual difference variables and the outcomes of interest. For example, individuals with an evening chronotype (natural preference for sleeping and waking late [28]) tend to have less healthy habits than those with a morning chronotype [29], and they may also be more likely to engage in bedtime media use, which in turn impacts their sleep. The DSMM also recognises that media effects can be conditional, therefore individual difference variables should also be considered as moderators of media–outcome relationships. For example, younger people might exhibit stronger reactions to social media than older people [30], which would mean that age functions as a moderator of media use effects.

We aimed to extend existing research on bedtime media use and sleep in adults using the DSMM as a framework. First, we aimed to examine associations between bedtime media use and various sleep outcomes, taking a range of covariates into account, including prior sleep measures, mental health, and other health behaviours (total leisure screen time, physical activity, alcohol consumption, and smoking). In light of recent findings that associations between total screen time and sleep among adolescents vary by media type [31], we also examined associations for different types of bedtime media. Second, we aimed to examine whether bedtime media use mediates associations between individual susceptibility factors (such as age, chronotype, and mood) and sleep outcomes, and whether individual susceptibility factors moderate associations between bedtime media use and sleep. To address these aims, we use data from a population-based cohort of adults.

2. Methods

2.1. Participants

Data were drawn from the Specchio cohort, a population-based digital study launched in December 2020 to follow up serosurvey participants in Geneva, Switzerland [32]. In June 2023, participants were invited by email to complete a questionnaire assessing media use and sleep (10,402 individuals). Among these adults, 4188 completed the questionnaire (total response rate 40 %); all these participants provided complete data on the measures of bedtime media use and sleep.

The Specchio study was approved by the Cantonal Research Ethics Commission of Geneva (CCER project ID 2020–00881).

2.2. Measures

2.2.1. Bedtime media use

Participants were asked to report how often they used a screen in the 30 minutes before going to sleep at night for each of the following activities: 1) working or studying, 2) watching a film, series, programme or documentary, 3) consulting or communicating via social networks such as Facebook, Twitter, Instagram, WhatsApp, TikTok, Tinder, 4) playing games (online or offline; alone or in a network), and 5) browsing the internet or applications dedicated to online shopping. The questions were based on those used in previous research examining the effects of media use in adolescents and young adults [21,31]. Response options ranged from 1 (never) to 6 (very often). The frequency of any bedtime media use was identified using participants responses to these questions and categorised as 'never or rarely', 'sometimes', and 'often or very often', in line with previous research [21].

2.2.2. Pittsburgh sleep quality index

The Pittsburgh Sleep Quality Index (PSQI) is a 19-item self-report measure that captures seven components of sleep quality over the past month: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction [33]. The scores for each component (0–3) are summed to yield a total score ranging from 0 to 21, with higher scores indicating poorer sleep quality. Internal consistency of the total score was good in the study sample ($\alpha = 0.70$). A PSQI score ≥ 5 was used to identify poor sleep quality [33]. A long sleep latency was defined as more than 30 minutes at least 3 times a week, based on previous associations with mortality [34]. A short sleep duration was defined as < 7 h, based on recommendations from the National Sleep Foundation [35].

2.2.3. Insomnia severity index

The Insomnia Severity Index (ISI) is a 7-item screening tool for insomnia [36]. Respondents rate, on a 5-point scale (0–4), the severity of symptoms, their satisfaction with their sleep patterns, the degree to which insomnia interferes with daily functioning, how noticeable they feel their insomnia is to others, and the overall level of distress created by the sleep problem. The total score is the sum of the 7 items, where higher scores indicate more acute symptoms of insomnia. Internal consistency of the ISI was high in the study sample ($\alpha = 0.87$). An ISI score of 15–28 was used to define insomnia [36].

2.2.4. Epworth sleepiness scale

The Epworth Sleepiness Scale (ESS) is a widely used self-report measure of an individual's sleepiness [37]. Respondents rate, on a 4-point scale (0–3), their tendency to doze or fall asleep in eight different situations. The total ESS score is the sum of the 8 items, with higher scores reflecting higher sleep propensity in daily life, or higher 'daytime sleepiness'. Internal consistency of the ESS was high in the study sample ($\alpha = 0.81$). An ESS score >9 was used to indicate excessive daytime sleepiness [37].

2.2.5. Bedtimes and rise times

Respondents indicated at what time they usually went to bed at night and got up in the morning. For the analyses, hours were counted from 0 to 24, and hours after midnight were counted as 25 (for 1:00), 26 (for 2:00), etc. Minutes were divided by 60 [22]. A late bedtime was defined as midnight or later, based on previous associations with cardiovascular events and mortality [38]. Rise time was modelled as a continuous variable as there is currently no recommendation on the optimal rise time [39].

2.2.6. Covariates

Covariates included age (in years), sex (male, female), education level, living situation (with others, alone), comorbidities (none, one, two or more), body mass index (BMI), total leisure screen time (hours per day), physical activity, binge drinking, smoking (non-smoker, former smoker, current smoker), chronotype (morning type, evening type, or neither type using the reduced Morningness Eveningness questionnaire [rMEQ] [40]), anxiety and depressive symptoms (using the 4-item Patient Health Questionnaire [PHQ-4] [41]), and prior sleep measures. Education level was categorised as primary (none or compulsory education), secondary (high school diploma or vocational training), or tertiary (university level qualification). BMI was calculated using self-reported height and weight (kg/m2). As per physical activity guidelines [42,43], physical activity level was defined as: active (moderate activity (of 30 min) at least 5 times per week OR vigorous activity at least twice a week), partially active (moderate activity (of 30 min) 1–4 times per week OR vigorous activity once a week), and inactive (no moderate or vigorous activity). Binge drinking was drinking six or more alcoholic beverages on the same occasion at least once per month (question from The Alcohol Use Disorders Identification Test-Concise (AUDIT-C) [44]). Prior sleep measures included ISI scores (assessed in June 2021) and subjective sleep quality (assessed in May 2022). The other covariates were assessed by questionnaire during the period March to May 2023.

2.3. Statistical analyses

Statistical analyses were conducted using Stata version 16 (StataCorp LLC, College Station, TX). Proportions and 95 % confidence intervals (CIs) were calculated to estimate the prevalence of bedtime media use.

Logistic regression was used to examine associations between bedtime media use and each of the sleep outcomes (late bedtime, long sleep latency, short sleep duration, poor sleep quality, insomnia, and excessive daytime sleepiness). Linear regression was used to examine associations with rise times. The first set of models examined associations between any bedtime media use and each sleep outcome; the second set examined associations between different types of bedtime media use and the sleep outcomes. For the latter, the different types of bedtime media use were entered together in the same model (as correlations between media types were small to moderate (Pearson's r range = 0.03–0.44)).

We examined three models per sleep outcome in a stepped approach. Model 1 was adjusted for sociodemographic factors (age, sex, educational attainment, living arrangement) and health status (comorbidities, and BMI). Model 2 additionally included health behaviours that likely covary with bedtime media use (smoking, alcohol consumption, physical activity, and total leisure time media use). Model 3 additionally included individual factors that may draw some people to media use (anxiety and depressive symptoms, chronotype, and prior sleep). Additional adjustment for work status (working, not working) did not change the pattern of results so these were not included in the final regression models. Data were missing for 481 participants (11 % of the sample) on one or more covariates (for 17 participants on sociodemographic covariates and comorbidities, 200 participants on health behaviours, and 382 participants on prior sleep quality), therefore a supplementary analysis imputed missing data on the covariates using multivariate imputation by chained equations (20 imputed data sets [45]).

Structural equation modelling with maximum likelihood estimation was used to examine the degree to which bedtime media use mediated the association between individual susceptibility factors (age, chronotype, and mental health) and continuous sleep outcomes (one model per sleep outcome) after adjustment for all covariates (model 3). A mediating effect was indicated by the presence of a significant indirect effect (the product of the direct paths) [46]. The Monte Carlo method (5000 samples) was used to estimate standardised indirect effects with 95 % confidence intervals [47]. As an indirect effect is the product of two direct paths, 0.003 (0.05 × 0.05) is a small but meaningful indirect effect, 0.01 (0.10 × 0.10) is a moderate indirect effect, and 0.06 (0.25 × 0.25) is a large indirect effect [48].

To examine whether individual susceptibility factors moderate associations between bedtime media use and sleep outcomes, interaction terms were created by multiplying bedtime media use by age (continuous and categorical), chronotype, and mental health, respectively. Supplementary analyses tested work status as a moderating factor. A statistically significant interaction term in the prediction of sleep indicates the presence of a moderating effect. Interaction effects were tested in fully adjusted models (model 3) and probed using simple slope analysis.

3. Results

3.1. Sample characteristics

Participants were on average 55 years old (SD 13; range 19–94 years), 59 % were women, 66 % were educated to tertiary level, and 26 % had one or more comorbidities. Compared to those invited to complete the questionnaire (N = 10,402), respondents were significantly older (mean age 55 years versus 50 years, $p < 0.001$), a greater proportion were educated to tertiary level (66 % versus 64 %, $p < 0.001$), and a greater proportion had comorbidities (26 % versus 23 %, $p < 0.001$). There was no significant difference in the distribution of sex, sleep duration, or the use of sleep medication between groups.

Table 1 shows characteristics of the overall sample, and by bedtime media use and sleep quality (PSQI score ≥5). Characteristics associated with bedtime media use at the univariate level were younger age, higher BMI, unhealthy behaviours (smoking, binge drinking, less physical activity, more total leisure screen time), poorer mental health, an evening chronotype, a later bedtime, a later rise time, prior sleep measures (poorer sleep quality, higher ISI scores), and current sleep measures (poorer sleep quality, higher ISI scores, and more daytime sleepiness). Characteristics associated with poorer sleep quality at the univariate level were younger age, female sex, lower education level, living alone, poorer physical health (comorbidities, higher BMI), unhealthy behaviours (smoking, binge drinking, less physical activity, more total leisure screen time), poorer mental health, an evening chronotype, and poorer prior sleep measures (sleep quality, ISI scores).

3.2. Prevalence of bedtime media use

Fig. 1 shows the prevalence of bedtime media use (any type) among adults. Around two thirds (60.3 % [95 % CI 58.9, 61.8]) of adults frequently engaged in bedtime media use, while 21.7 % (20.5, 23.0) never or rarely did so. Among the subgroups examined, frequent bedtime media use was most often reported among younger adults (≤35 years): 80 % (75.4, 83.9) compared with 62.7 % (60.9, 64.5) among middle-aged adults, and 47.2 % (44.1, 50.3) among older adults. Prevalence of frequent bedtime media use was similar among men (59.2 % [56.9, 61.6]) and women (61.1 % [59.2, 63]).

Fig. 2 shows the prevalence of bedtime media use by type of activity. The most common was watching a film or programme (42.0 % [40.6, 43.6] frequently did so), followed by social media use (26.7 % [25.3, 28.0]), shopping or browsing the internet (11.2 % [10.3, 12.2]),

Table 1
Characteristics of the total study sample (N = 4188) by bedtime media use and sleep quality. Data are presented as mean (SD) for continuous measures, and % (n) for categorical measures.

		Bedtime media use				Sleep quality, PSQI[a]		
	Total	Never, rarely	Sometimes	Often, very often	p-value	Good sleep quality	Poor sleep quality	p-value
	N = 4188	N = 908	N = 752	N = 2528		N = 2161	N = 2027	
Age, years	54.7 (13.3)	59.7 (12.3)	55.5 (12.7)	52.6 (13.3)	<0.001	55.2 (13.2)	54.1 (13.3)	0.011
Age category								
Older, ≥65 years	24.1 (1009)	37.0 (336)	26.2 (197)	18.8 (476)	<0.001	26.2 (567)	21.8 (442)	0.001
Middle-aged, 36–64 years	67.8 (2839)	60.5 (549)	67.8 (510)	70.4 (1780)		66.5 (1436)	69.2 (1403)	
Younger, ≤35 years	8.1 (340)	2.5 (23)	6.0 (45)	10.8 (272)		7.3 (158)	9.0 (182)	
Gender					0.28			<0.001
Male	40.2 (1678)	39.4 (357)	43.5 (327)	39.4 (994)		44.2 (951)	35.9 (727)	
Female	59.4 (2483)	60.3 (546)	55.9 (420)	60.2 (1517)		55.6 (1197)	63.6 (1286)	
Other	0.4 (16)	0.3 (3)	0.5 (4)	0.4 (9)		0.3 (6)	0.5 (10)	
Education level					0.22			0.002
Tertiary	65.8 (2744)	65.0 (588)	68.1 (511)	65.4 (1645)		68.1 (1467)	63.3 (1277)	
Secondary	30.9 (1289)	30.7 (278)	28.8 (216)	31.6 (795)		29.1 (627)	32.8 (662)	
Primary	3.3 (138)	4.3 (39)	3.1 (23)	3.0 (76)		2.7 (59)	3.9 (79)	
Living arrangement					0.84			0.005
With others	83.3 (3479)	83.1 (753)	84.0 (631)	83.1 (2095)		84.9 (1828)	81.6 (1651)	
Alone	16.7 (698)	16.9 (153)	16.0 (120)	16.9 (425)		15.1 (326)	18.4 (372)	
Comorbidities					0.76			<0.001
None	73.5 (3071)	72.8 (660)	73.1 (549)	73.9 (1862)		77.7 (1674)	69.1 (1397)	
One	14.1 (589)	13.6 (123)	14.8 (111)	14.1 (355)		13.1 (282)	15.2 (307)	
Two or more	12.4 (517)	13.6 (123)	12.1 (91)	12.0 (303)		9.2 (198)	15.8 (319)	
BMI	24.8 (4.2)	24.2 (3.8)	24.7 (4.3)	25.0 (4.4)	<0.001	24.6 (4.1)	24.9 (4.4)	0.027
Smoking status					0.007			0.002
Never smoked	55.0 (2299)	54.9 (497)	60.7 (456)	53.4 (1346)		57.3 (1235)	52.5 (1064)	
Former smoker	29.6 (1236)	30.7 (278)	26.2 (197)	30.2 (761)		28.8 (621)	30.4 (615)	
Current smoker	15.4 (644)	14.5 (131)	13.0 (98)	16.5 (415)		13.8 (298)	17.1 (346)	
Binge drinking					<0.001			0.001
Less than once a month	83.9 (3345)	87.4 (768)	85.4 (612)	82.1 (1965)		85.7 (1775)	81.9 (1570)	
Once a month or more	16.1 (643)	12.6 (111)	14.6 (105)	17.9 (427)		14.3 (297)	18.1 (346)	
Physical activity level					<0.001			<0.001
Active	49.0 (1953)	55.3 (486)	49.9 (358)	46.4 (1109)		52.9 (1096)	44.7 (857)	
Partially active	47.6 (1897)	40.3 (354)	46.2 (331)	50.7 (1212)		43.1 (892)	52.5 (1005)	
Inactive	3.5 (138)	4.4 (39)	3.9 (28)	3.0 (71)		4.1 (84)	2.8 (54)	
Total leisure screen time					<0.001			<0.001
<2 h per day	56.9 (2385)	76.8 (697)	69.3 (521)	46.2 (1167)		61.1 (1320)	52.5 (1065)	
≥2 h per day	43.1 (1803)	23.2 (211)	30.7 (231)	53.8 (1361)		38.9 (841)	47.5 (962)	
PHQ4 score	2.1 (2.5)	1.5 (2.2)	2.1 (2.4)	2.4 (2.6)	<0.001	1.2 (1.7)	3.2 (2.9)	<0.001
Chronotype, rMEQ					<0.001			<0.001
Morning type	39.9 (1671)	48.5 (440)	40.0 (301)	36.8 (930)		42.4 (916)	37.2 (755)	
Neither type	53.1 (2225)	49.2 (447)	53.9 (405)	54.3 (1373)		52.1 (1126)	54.2 (1099)	
Evening type	7.0 (292)	2.3 (21)	6.1 (46)	8.9 (225)		5.5 (119)	8.5 (173)	
ISI score, 2021	7.4 (5.5)	6.5 (5.3)	7.0 (5.4)	7.9 (5.6)	<0.001	4.9 (4.4)	10.1 (5.3)	<0.001
Sleep quality, 2022	1.1 (0.7)	1.0 (0.7)	1.1 (0.7)	1.2 (0.7)	<0.001	0.8 (0.6)	1.5 (0.6)	<0.001
ISI score	7.7 (5.9)	6.5 (5.5)	7.4 (5.8)	8.2 (5.9)	<0.001	3.9 (3.3)	11.7 (5.3)	<0.001
PSQI score	6.0 (3.3)	5.5 (3.2)	5.8 (3.4)	6.2 (3.3)	<0.001	3.4 (1.3)	8.7 (2.5)	<0.001
Bedtime	23.1 (1.0)	22.8 (0.8)	23.0 (0.9)	23.2 (1.0)	<0.001	23.1 (0.9)	23.1 (1.0)	0.54
Rise time	6.9 (1.1)	6.8 (1.0)	6.8 (1.0)	6.9 (1.1)	0.007	6.9 (1.0)	6.8 (1.2)	0.002
Sleep latency, mins	18.7 (19.9)	16.9 (14.8)	18.0 (18.2)	19.5 (21.9)	0.002	11.5 (8.6)	26.3 (25.1)	<0.001
Sleep duration, hrs	6.9 (1.0)	7.0 (1.0)	6.9 (1.1)	6.8 (1.0)	<0.001	7.4 (0.8)	6.4 (1.0)	<0.001
ESS score	8.1 (4.6)	6.8 (4.4)	7.9 (4.7)	8.6 (4.7)	<0.001	7.0 (4.1)	9.3 (4.9)	<0.001

PHQ4 = 4-item Patient Health Questionnaire; rMEQ = reduced Morningness-Eveningness Questionnaire; ISI = Insomnia Severity Index; ESS = Epworth Sleepiness Scale.

[a] A score of 5 or more on the Pittsburgh Sleep Quality Index (PSQI) is used to identify poor sleepers.

working or studying (8.9 % [8.0, 9.8]), and playing games (8.6 % [7.8, 9.5]).

When examining by age group, watching a film or programme was the most prevalent bedtime media activity among middle-aged (43.7 % [41.9, 45.6]) and older adults (33.7 % [30.8, 36.7]), followed by social media use (27.2 % [25.6, 28.8] and 14.7 % [12.6, 17.0], respectively). While for younger adults, engaging in social media was the most prevalent bedtime media activity (58.2 % [52.9, 63.4]), followed by watching a film or programme (52.6 % [47.3, 57.9]). Prevalence of watching a film or programme was similar among men (41.8 % [39.4, 44.2]) and women (42.2 % [40.3, 44.2]), as was browsing the internet (11.0 % [9.6, 12.6] and 11.1 % [10.0, 12.5], respectively). However, engaging in social media was more prevalent among women (28.4 % [26.7, 30.2]) than men (24.1 % [22.1, 26.2]), as was playing games (9.7 % [8.6, 10.9] and 6.9 % [5.8, 8.2], respectively). On the contrary, working in the 30 minutes before going to sleep at night was more prevalent among men (10.7 % [9.3, 12.3]) than women (7.6 % [6.6, 8.7]).

3.3. Associations between bedtime media use and sleep outcomes

Fig. 3 shows the associations between bedtime media use (any type) and sleep outcomes. Frequent bedtime media use was associated with a late bedtime, later rise times (standardised $\beta = 0.10$ (0.07, 0.14), $p < 0.001$), long sleep latency, poor sleep quality, insomnia, and excessive daytime sleepiness, adjusting for age, sex, education, living arrangement, comorbidities, and BMI. Associations were reduced but held after further adjustment for other health behaviours – namely physical

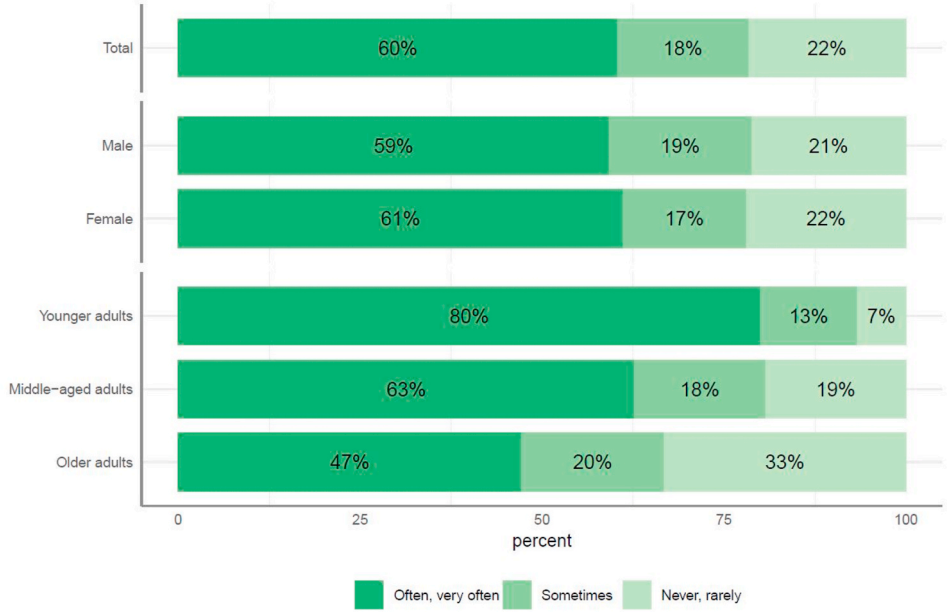

Fig. 1. Prevalence of bedtime media use for the total sample, and by age group and sex (N = 4188). Younger adults (≤35 years), middle-aged adults (36–64 years), older adults (>65 years).

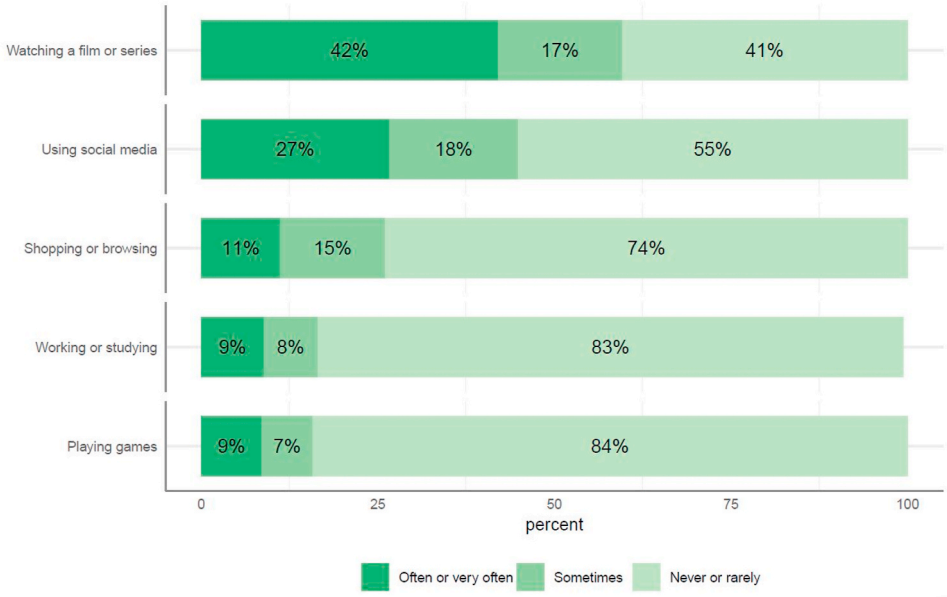

Fig. 2. Prevalence of bedtime media use by type of media (N = 4188).

activity level, binge drinking, smoking, and total leisure screen time. When adding mental health, chronotype, and prior sleep measures to the models, the associations held for a late bedtime, later rise times (standardised β = 0.06 (0.03, 0.10, p < 0.01), short sleep duration, and excessive daytime sleepiness, but not for long sleep latency, poor sleep quality, or insomnia. Sleep duration partly mediated the association between bedtime media use and daytime sleepiness in the fully adjusted model (indirect effect β [95 % CI] = -0.006 [0.001, 0.011], p = 0.017).

When examining associations between bedtime media use and sleep outcomes by media type, watching a film or programme, social media use, and playing games were associated with excessive daytime sleepiness in the fully adjusted models; while engaging in work before going to sleep was associated with poor sleep quality, insomnia, and short sleep duration (see Table 2).

Supplementary analyses showed that the pattern of results was the same when imputing missing data on the covariates, and when modelling all outcomes as continuous variables (see Supplementary Table 1).

3.4. *Bedtime media use mediates associations between individual susceptibility factors and sleep*

All tested models had acceptable fit (RMSEA ≤0.06, CFI ≥0.95, and TLI ≥0.95 [49]; see Table 3 for standardised coefficients for direct effects).

In the fully adjusted mediation model with daytime sleepiness as the outcome, younger age was associated with frequent bedtime media use and more daytime sleepiness; and there was a moderate indirect effect indicating that bedtime media use partly mediated the association

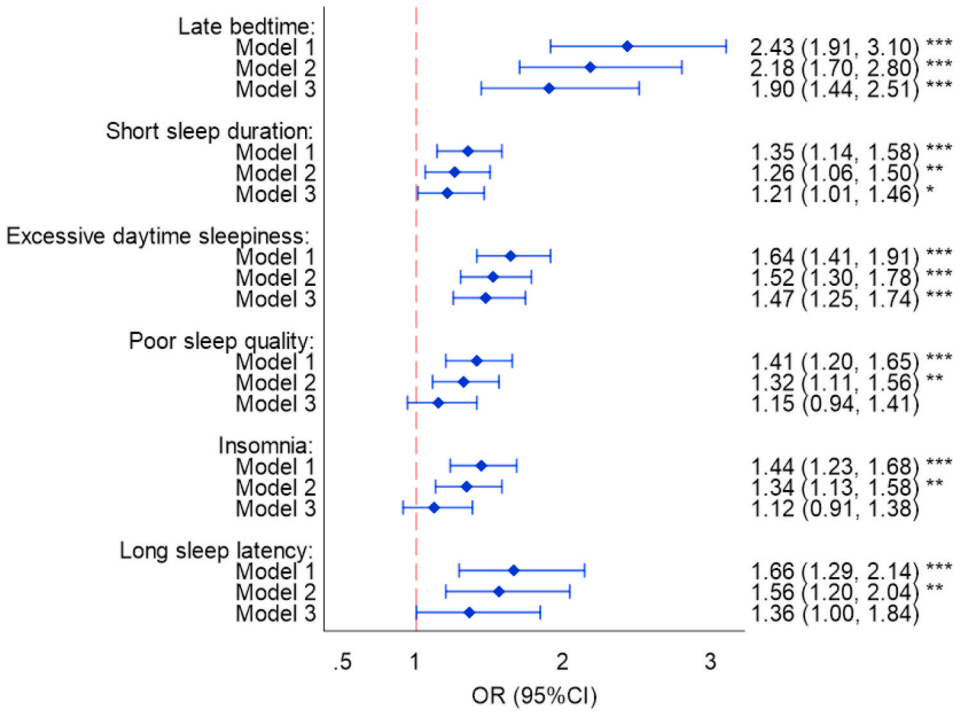

Fig. 3. Associations between bedtime media use and sleep outcomes. Results are ORs and 95 % confidence intervals. Model 1 adjusted for age, sex, education, living arrangement, comorbidities, and BMI; smoking, binge drinking, physical activity level, and total leisure screen time were added in model 2; mental health, chronotype, and prior sleep quality were added in model 3. ORs are for often/very often engaging in bedtime media use versus never/rarely engaging in bedtime media use. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Late bedtime = midnight or later; short sleep duration = < 7 h; excessive daytime sleepiness = Epworth Sleepiness Scale (ESS) score >9; poor sleep quality = Pittsburgh Sleep Quality Index (PSQI) score ≥5; insomnia = Insomnia Severity Index (ISI) score 15–28; long sleep latency = > 30 minutes ≥ 3 times a week.

between age and daytime sleepiness (β [95 % CI] = -0.017 [−0.025, −0.010], $p < 0.001$). Having an evening chronotype (compared to a morning chronotype or neither type) was associated with frequent bedtime media use, but not daytime sleepiness. There was a small indirect effect indicating that bedtime media use partly mediated the association between chronotype and daytime sleepiness (β = 0.006 [0.003, 0.011], $p = 0.003$).

In the fully adjusted mediation model with bedtime as the outcome, older age was associated with later bedtimes (which did not hold after additional adjustment for work status, $p = 0.480$); and there was a moderate indirect effect indicating that bedtime media use partly mediated the association between age and bedtime (β [95 % CI] = -0.020 [−0.028, −0.013], $p < 0.001$), which held after additional adjustment for work status ($p < 0.001$). Having an evening chronotype (compared to a morning chronotype or neither type) was associated with later bedtimes; and there was a small indirect effect indicating that bedtime media use partly mediated the association between chronotype and bedtime (β = 0.007 [0.003, 0.011], $p = 0.002$).

In the fully adjusted mediation model with rise time as the outcome, older age was associated with later rise times (which did not hold after additional adjustment for work status, $p = 0.074$); and there was a moderate indirect effect indicating that bedtime media use partly mediated the association between age and rise time (β [95 % CI] = -0.009 [−0.016, −0.003], $p = 0.007$), which held after additional adjustment for work status ($p = 0.010$). Having an evening chronotype (compared to a morning chronotype or neither type) was associated with later rise times; and there was a small indirect effect indicating that bedtime media use partly mediated the association between chronotype and rise time (β = 0.003 [0.001, 0.007], $p = 0.027$).

In the fully adjusted model with sleep duration as the outcome, there was a small indirect effect indicating that bedtime media use partly mediated the association between age and sleep duration (β [95 % CI] = 0.008 [0.001, 0.015], $p = 0.025$). For evening chronotype (compared to a morning chronotype or neither type), the indirect effect did not reach statistical significance ($p = 0.060$).

There were no significant indirect effects when testing sleep quality, insomnia symptoms, or sleep latency as outcomes. There were no significant indirect effects for mental health in any of the tested models.

3.5. *Mental health moderates associations between bedtime media use and sleep quality*

There was a significant mental health x bedtime media use interaction predicting sleep quality (β = −0.15; 95 % CI [−0.21, −0.08]; $p < 0.001$) and insomnia symptoms (β = −0.09; 95 % CI [−0.15, −0.04]; $p = 0.001$), but not for the other sleep outcomes. Simple slope analysis showed that frequent bedtime media use was associated with poorer sleep quality among those with better mental health (marginal effect = 0.46 [0.19, 0.72], $p = 0.001$), but with better sleep quality among those with poorer mental health (marginal effect = −0.48 [−0.84, −0.12], $p = 0.010$). Frequent bedtime media use was also associated with insomnia symptoms among those with better mental health (marginal effect = 0.61 [0.17, 1.06], $p = 0.007$), while there was no association among those with poorer mental health.

There were no significant interaction effects for age (continuous or categorical) or chronotype. Supplementary analysis showed that, although work status (working) was associated with shorter sleep duration, more insomnia symptoms, and more daytime sleepiness in the fully adjusted models, it did not moderate the association between bedtime media use and any of the sleep outcomes.

4. Discussion

In this adult population-based cohort study, we found that frequent bedtime media use was associated with a late bedtime, later rise times, a short sleep duration, and excessive daytime sleepiness after adjustment

Table 2
Associations between type of bedtime media use and sleep outcomes. Results are ORs and 95 % confidence intervals (standardised betas for rise times).

	Watching a film or programme	Using social media	Shopping or browsing	Working or studying	Playing games
Late bedtime					
Model 1	1.39 (1.16, 1.67) ***	1.19 (0.96, 1.48)	1.02 (0.78, 1.34)	1.78 (1.37, 2.30) ***	1.85 (1.42, 2.39) ***
Model 2	1.26 (1.03, 1.53) *	1.16 (0.93, 1.45)	1.04 (0.78, 1.37)	1.78 (1.37, 2.33) ***	1.64 (1.25, 2.15) ***
Model 3	1.29 (1.03, 1.61) *	1.15 (0.89, 1.49)	0.92 (0.66, 1.27)	1.75 (1.29, 2.38) ***	1.65 (1.21, 2.26) **
Rise time, hours					
Model 1	0.05 (0.02, 0.08) **	0.07 (0.03, 0.11) ***	0.00 (−0.03, 0.03)	0.03 (−0.01, 0.06)	0.02 (−0.01, 0.05)
Model 2	0.04 (−0.00, 0.07)	0.05 (0.01, 0.09) **	0.01 (−0.02, 0.05)	0.02 (−0.01, 0.06)	0.02 (−0.01, 0.06)
Model 3	0.03 (−0.00, 0.06)	0.04 (0.00, 0.07) *	0.00 (−0.03, 0.04)	0.01 (−0.02, 0.04)	0.02 (−0.01, 0.05)
Short sleep duration					
Model 1	1.20 (1.04, 1.38) *	0.98 (0.83, 1.16)	1.18 (0.95, 1.47)	1.47 (1.17, 1.83) **	1.27 (1.01, 1.59) *
Model 2	1.11 (0.96, 1.29)	0.97 (0.81, 1.16)	1.16 (0.92, 1.45)	1.49 (1.18, 1.87) **	1.20 (0.95, 1.52)
Model 3	1.08 (0.92, 1.28)	0.94 (0.77, 1.14)	1.08 (0.84, 1.38)	1.50 (1.16, 1.92) **	1.22 (0.95, 1.58)
Excessive daytime sleepiness					
Model 1	1.35 (1.18, 1.53) ***	1.26 (1.07, 1.48) **	1.01 (0.82, 1.25)	1.16 (0.94, 1.44)	1.30 (1.05, 1.62) *
Model 2	1.26 (1.10, 1.44) **	1.29 (1.09, 1.52) **	1.00 (0.81, 1.24)	1.14 (0.92, 1.42)	1.27 (1.01, 1.59) *
Model 3	1.24 (1.07, 1.43) **	1.23 (1.03, 1.46) *	1.00 (0.79, 1.26)	1.10 (0.87, 1.39)	1.37 (1.08, 1.74) **
Poor sleep quality					
Model 1	1.16 (1.01, 1.33) *	1.03 (0.87, 1.22)	1.33 (1.07, 1.65) *	1.63 (1.29, 2.05) ***	1.08 (0.86, 1.36)
Model 2	1.08 (0.93, 1.25)	1.02 (0.86, 1.22)	1.32 (1.05, 1.65) *	1.62 (1.28, 2.06) ***	0.99 (0.78, 1.26)
Model 3	1.01 (0.85, 1.22)	0.89 (0.72, 1.11)	1.22 (0.92, 1.62)	1.68 (1.26, 2.24) ***	1.10 (0.82, 1.47)
Insomnia					
Model 1	1.19 (1.04, 1.36) **	1.06 (0.90, 1.24)	1.29 (1.05, 1.58) *	1.47 (1.19, 1.82) ***	1.01 (0.81, 1.25)
Model 2	1.13 (0.98, 1.30)	1.04 (0.87, 1.23)	1.24 (1.01, 1.54) *	1.50 (1.21, 1.87) ***	0.95 (0.76, 1.19)
Model 3	1.01 (0.85, 1.21)	0.87 (0.70, 1.07)	1.04 (0.80, 1.37)	1.50 (1.14, 1.97) **	1.06 (0.81, 1.39)
Long sleep latency					
Model 1	1.43 (1.17, 1.75) **	1.09 (0.85, 1.39)	1.00 (0.73, 1.36)	1.32 (0.97, 1.78)	1.04 (0.75, 1.43)
Model 2	1.32 (1.06, 1.64) *	1.11 (0.86, 1.43)	0.98 (0.71, 1.36)	1.26 (0.92, 1.73)	0.98 (0.70, 1.37)
Model 3	1.15 (0.89, 1.47)	0.99 (0.73, 1.32)	1.05 (0.72, 1.52)	1.26 (0.87, 1.82)	0.95 (0.64, 1.39)

Model 1 adjusted for all types of bedtime media use plus age, sex, education, living arrangement, comorbidities, and BMI; smoking, binge drinking, physical activity level, and total leisure screen time were added in model 2; mental health, chronotype, and prior sleep quality were added in model 3.
ORs/betas are for often/very often engaging in bedtime media use versus never/rarely engaging in bedtime media use.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Late bedtime = midnight or later; short sleep duration = < 7 h; excessive daytime sleepiness = Epworth Sleepiness Scale (ESS) score >9; poor sleep quality = Pittsburgh Sleep Quality Index (PSQI) score ≥5; insomnia = Insomnia Severity Index (ISI) score 15–28; long sleep latency = > 30 minutes ≥ 3 times a week.

Table 3
Standardised beta coefficients for the fully adjusted mediation models.

Individual susceptibility factors	Bedtime media use	Daytime sleepiness		Bedtime		Rise time		Sleep duration	
	Direct effect	Direct effect	Indirect effect[a]	Direct effect	Indirect effect[a]	Direct effect	Indirect effect[a]	Direct effect	Indirect effect[a]
Age, years	−0.167***	−0.101***	−0.017***	0.061***	−0.020***	0.219***	−0.009**	−0.029	0.008*
Evening chronotype[b]	0.057***	−0.003	0.006**	0.371***	0.007**	0.283***	0.003*	−0.012	−0.003*
Mental health, PHQ4 score	0.021	0.216***	0.002	−0.013	0.002	0.018	0.001	−0.067***	−0.001

Standardised betas reported. *p < 0.05, **p < 0.01, ***p < 0.001. PHQ4 = 4-item Patient Health Questionnaire. Models included age, chronotype, and mental health as well as sex, education, living arrangement, comorbidities, BMI, physical activity, smoking, binge drinking, total leisure screen time, and prior sleep quality as covariates.

[a] via bedtime media use.

[b] Compared to a morning chronotype or neither type.

for sociodemographic factors, comorbidities, other health behaviours, mental health, chronotype, and prior sleep measures. These findings extend previous epidemiological research on bedtime media use and sleep in adults [19–23] that took a limited range of covariates into account. Moreover, frequent bedtime media use partly mediated the association between individual susceptibility factors (age and chronotype) and these sleep outcomes. Mental health moderated the association between frequent bedtime media use and sleep quality and insomnia, such that the former was associated with poorer sleep quality and insomnia symptoms among individuals with better mental health, but with better sleep quality (and no association with insomnia symptoms) among those with poorer mental health.

Our findings are in line with the notion that bedtime media use can delay sleep onset, rendering users susceptible to insufficient sleep [16,50]. Recent research examining patterns of social media posting in 44,000 Reddit users found that users were most likely to be active on Reddit after their bedtime (and therefore awake) on nights that they posted to Reddit shortly before bedtime; suggesting that there is likely some causal effect of bedtime media use on delayed sleep onset [50]. In the experimental research available, there was no impact of bedtime media use on objective or subjective sleep parameters [51]. However, media use was limited to 30 minutes in the study procedure, while in real life it often exceeds this time, and wake-up times are often determined by school hours or working schedules. Taken together, these findings indicate that people should limit the use of screens at bedtime to get sufficient sleep.

Our finding that bedtime media use was associated with short sleep duration is in line with the sleep displacement hypothesis, according to which bedtime media can displace sleep time through delayed bedtime [16]. However, the effect was somewhat smaller than expected, which could be explained by our finding that bedtime media use was also associated with later rise times, albeit to a lesser extent – a process called time shifting [52]. Other studies on media use and sleep have also found that media use can coincide with later bedtimes and later rise times [53,54], suggesting that individuals with externally determined early rise times are most susceptible to adverse effects of bedtime media on sleep duration. In our sample, work status did not moderate the association between bedtime media use and sleep duration, which could be because working adults had earlier bedtimes (as well as earlier rise times) than those not working.

Sleep duration only partly explained the association between bedtime media use and daytime sleepiness, suggesting that other mechanisms are also involved. Exposure to bright light from screens is a possible mechanism as it has been shown to delay the body's melatonin production, decrease the time spent in deep sleep, and reduce next-morning alertness [55–57]. It has been suggested that novel approaches to minimise the effects of nocturnal blue light exposure, such as devices with blue intensity modulation technology [18], may be particularly effective at improving sleep health among those who are unlikely to limit the use of screens at bedtime, even when recommendations are made by clinicians [56]. As the mere presence of devices has been associated with sleep outcomes [11], simply removing these devices from the bedroom could be an effective strategy.

In the fully adjusted mediation models, younger adults, and those with an evening chronotype, were more likely to engage in frequent bedtime media use, which in turn predicted bedtimes, rise times, sleep duration, and daytime sleepiness. The mediating effects held when taking other important health behaviours into account, such as total leisure screen time; but given that health behaviours tend to covary [24], an overall reduction in screen time could have a positive impact on bedtime screen use among younger adults and those with an evening chronotype.

Frequent bedtime media use was not associated with sleep latency in our study, nor when assessed by type of bedtime media. Associations between bedtime media use and sleep disturbance, including long sleep latency, may be particularly evident when media use activates pre-sleep arousal, making it difficult to fall asleep [17]. Although we did not see an association with sleep latency, associations between bedtime media use and insomnia were strongest for working or studying before going to sleep, which is in line with the notion that some bedtime media activities have stronger effects on pre-sleep arousal than others [31]. Actively browsing the internet or writing on social media is also more likely to be psychologically arousing than more passive activities such as watching a film or programme. However, we did not distinguish between active and passive media use in our questions (e.g. it is possible to be active or passive on social media), and we recommend further research on this topic does so.

Consistent with research on total media use and sleep [25,26], we found that associations between bedtime media use and sleep quality or insomnia did not hold when adjusting for prior sleep and mental health. Upon further examination, and consistent with the DSMM, we found that mental health moderated the association between bedtime media use and these sleep outcomes. Bedtime media use was associated with poorer sleep quality and insomnia symptoms among individuals with better mental health, but with slightly better sleep quality (and no association with insomnia symptoms) among individuals with poorer mental health. These findings could be explained by use of bedtime media as a sleep aid among individuals with poorer mental health. Indeed, previous research has shown that media use can be an adaptive strategy for managing psychological discomfort [58,59] and arousal [60,61]. However, while bedtime media use may be a temporary distraction or way of coping among people with poorer mental health, it could have adverse consequences in the long run [54]. In the present study, bedtime media use was associated with later bedtimes and more daytime sleepiness for all levels of mental health. It is therefore recommended that individuals replace bedtime screen use with better sleep hygiene activities, such as relaxation techniques [51], reading a book, listening to music, and other health behaviours that promote sleep [62]. Given the strong association between mental health and sleep quality and insomnia, addressing mental health issues with a combination of

approaches is important alongside any changes in bedtime media use.

4.1. Strengths and limitations

Study strengths include the use of population-based data, consideration of different types of bedtime media, assessment of various sleep outcomes, as well as a range of covariates not included in previous studies, and examination of potential mediating and moderating effects, which was guided by theory. However, a limitation is that we did not measure media content or contextual aspects of media use before bed, such as the location of bedtime media use, the device used, and session length, which likely moderate the association between bedtime media use and sleep [63]. Although we took prior sleep and mental health into account, as well as total leisure screen time, we did not have repeat measures of bedtime media use, nor could we test whether bedtime media use was associated with sleep or mental health trajectories. We could not test all aspects of the differential susceptibility to media effects model, such as transactional media effects [27], nor did we test for all possible interaction effects. We did not have measures of other individual difference factors that may be important such as intelligence or personality. Although we used established, validated measures of sleep, the use of objective sleep parameters would provide further insight. Two thirds of our sample were educated to tertiary level, which is higher than that in the general population. Participants in this study may therefore be healthier or more resilient than those who did not participate, which could lead to an underestimation of the observed effects.

5. Conclusions

Frequent bedtime media use is associated with a late bedtime, later rise times, a short sleep duration, and excessive daytime sleepiness in adults, even after adjustment for other health behaviours, chronotype, mental health, and prior sleep measures. Younger adults, and those with an evening chronotype, are more likely to engage in frequent bedtime media use, which in turn predicts bedtime, rise time, and daytime sleepiness. Frequent bedtime media use is associated with poorer sleep quality and insomnia symptoms among those with better mental health, but not among individuals with poorer mental health who likely require additional support to improve their sleep quality.

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Ethics approval and consent to participate

The Specchio study was approved by the Cantonal Research Ethics Commission of Geneva (CCER project ID 2020–00881).

Availability of data and materials

The data are available on request from the corresponding author.

CRediT authorship contribution statement

Stephanie Schrempft: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Hélène Baysson:** Writing – review & editing, Project administration, Methodology. **Ambra Chessa:** Methodology. **Elsa Lorthe:** Writing – review & editing, Methodology. **María-Eugenia Zaballa:** Project administration, Methodology. **Silvia Stringhini:** Writing – review & editing, Funding acquisition. **Idris Guessous:** Writing – review & editing, Supervision, Funding acquisition. **Mayssam Nehme:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2024.06.029.

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