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Original Article

Two hours of evening reading on a self-luminous tablet vs. reading a physical book does not alter sleep after daytime bright light exposure

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ABSTRACT

Background: The use of electronic devices emitting blue light during evening hours has been associated with sleep disturbances in humans, possibly due to the blue light-mediated suppression of the sleep-promoting hormone melatonin. However, experimental results have been mixed. The present study therefore sought to investigate if reading on a self-luminous tablet during evening hours would alter sleepiness, melatonin secretion, nocturnal sleep, as well as electroencephalographic power spectral density during early slow-wave sleep.

Methods: Following a constant bright light exposure over 6.5 hours (~569 lux), 14 participants (six females) read a novel either on a tablet or as physical book for two hours (21:00–23:00). Evening concentrations of saliva melatonin were repeatedly measured. Sleep (23:15–07:15) was recorded by polysomnography. Sleepiness was assessed before and after nocturnal sleep. About one week later, experiments were repeated; participants who had read the novel on a tablet in the first experimental session continued reading the same novel in the physical book, and *vice versa*.

Results: There were no differences in sleep parameters and pre-sleep saliva melatonin levels between the tablet reading and physical book reading conditions.

Conclusions: Bright light exposure during daytime has previously been shown to abolish the inhibitory effects of evening light stimulus on melatonin secretion. Our results could therefore suggest that exposure to bright light during the day – as in the present study – may help combat sleep disturbances associated with the evening use of electronic devices emitting blue light. However, this needs to be validated by future studies with larger sample populations.

1. Introduction

As demonstrated by a recent survey involving 1508 participants, computers and other screen-based technological devices are frequently used in the evening (eg, tablets, smartphones) [1]. For instance, 96% of those younger than 30 years reported to use screen-based technological devices within one hour before trying to sleep [1]. These figures are alarming given that several epidemiological studies have associated evening use of screen-based technologies with impaired nocturnal sleep [2,3]. For instance, school-aged children with access to screen-based technological devices in their bedrooms sleep shorter, go to bed later, and feel less well-rested after sleep than those without access to technological devices in their bedrooms [4]. Given that impaired sleep has been linked to a variety of health problems [5–10], an important question is: how does the evening use of screen-based technological devices impact nocturnal sleep in humans?

The duration and timing of sleep has been proposed to be regulated by two interacting processes: *process S*, postulating that sleep pressure accumulates with extended wakefulness; and *process C*, proposing that sleep propensity increases at specific times of the day [11]. A factor that has been shown to play an important role in the regulation of sleep timing is ambient light, as it suppresses the production of the sleep-promoting pineal gland hormone

Abbreviations: BMI, body mass index; EEG, electroencephalography; PSG, polysomnography; EMG, electromyogram; EOG, electrooculogram; KSS, Karolinska Sleepiness Scale; LED, light emitting diode; N1 sleep, sleep stage 1; N2 sleep, sleep stage 2; REM, rapid eye movement; SWS, slow-wave sleep; SEM, standard error of mean; SD, standard deviation; SOL, sleep onset latency; SWA, slow-wave activity; TST, total sleep time; WASO, wake after sleep onset.

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melatonin, especially if the light is short-wavelength-enriched [12–15]. It is therefore reasonable to hypothesize that evening use of devices with light-emitting diode (LED) screens (eg, tablets) – which are also short-wavelength-enriched [16] – could alter the ability to fall and stay asleep. Previous studies have for instance demonstrated that short-wavelength-enriched light administered during evening hours attenuates the release of melatonin and decreases subjective sleepiness in humans [14]. Moreover, it has been shown that exposure to short-wavelength-enriched light close to bedtime delays sleep onset, increases time in stage 2 sleep (N2 sleep), prolongs slow-wave sleep (SWS) latency, and reduces time in rapid eye movement (REM) sleep [14,17]. Similar effects on pre-sleep melatonin and alertness as well as nocturnal sleep have also been observed following evening use of tablet computers [16,18]. For instance, in a previous study involving 12 young adults (six females) [16], a variety of effects of reading on a tablet computer vs. reading a physical book for four hours right before bedtime (over five consecutive days in each condition) was found on sleep parameters. This included a late-shifted pre-sleep rise in melatonin, decreased evening sleepiness, increased sleep onset latency (SOL), decreased minutes spent in REM sleep, and increased morning sleepiness.

However, there are also contrary results. For instance, an experimental study in which adolescents were allowed to use a tablet with full brightness for one hour before bedtime vs. one hour of tablet use with a short-wavelength filter, did not detect any effects on SOL, REM sleep nor any other sleep parameter [19]. A recent study with 16 participants (12 females) found that reading on an iPad in bed before trying to sleep did not increase SOL or sleep composition (that is, time spent in each sleep stage); however, sleepiness before turning the lights off to sleep was reduced, and early night slow-wave activity (SWA) – which is sensitive to homeostatic sleep pressure (process S) [11] – was reduced compared to reading a conventional book [20]. The latter observation is in line with a previous study where SWA during the first sleep cycle was reduced after evening blue-enriched polychromatic light exposure [21].

In light of these mixed results, the present study sought to investigate whether two hours of evening reading on a self-luminous tablet, preceded by a 6.5 hour period of constant bright light conditions (~569 lux), would alter evening and morning sleepiness, evening melatonin levels, time to fall asleep, total sleep time, and time in different sleep stages. Blue light exposure in the evening prior to sleep has been linked to reduced early night SWA [20,21], a frequency spectrum that is maximally expressed during SWS. We therefore also measured if evening tablet use would alter electroencephalography (EEG) power spectral density of SWS in the first 90 minutes (approximately corresponding to the first sleep cycle) after sleep onset.

2. Materials and methods

2.1. Participants

Fourteen healthy adults successfully completed the study. Similar sample sizes have been utilized in previous experiments investigating the influence of evening tablet use on nocturnal sleep in humans (n = 12 in Ref. [16] and n = 16 in Ref. [20], respectively).

A screening interview scheduled before experiments ensured that participants fulfilled the following study inclusion criteria: normal-weight (BMI <25 kg/m^2), right-handed, no color blindness or visual acuity, have not been diagnosed for psychiatric, neurologic, hormonal, metabolic, or sleep related diseases, no use of nicotine or drugs, not traveled between time zones one month before and during the study, habitually go to bed between 21:00 and 24:00, wake up between 06:00 and 10:00, total nocturnal sleep duration between seven and nine hours, and they had not read the book that was used in the study ("The Magicians" by Lev Grossman). All females were taking oral monophasic contraceptive pills containing gestagen and estrogen, otherwise they were free of medication, as were men. Finally, participants also completed the diurnal type scale assessing chronotype ([22], mean score ± SD, 16.8 ± 2.8).

Subjects participated in an adaptation night in our sleep laboratory at Uppsala Biomedical Center, Uppsala University, Uppsala, Sweden prior to, but not in direct connection to, the first experimental session. Participants were instructed to go to bed between 21:00 and 24:00, get up between 06:00 and 10:00, and to get seven to nine hours of sleep three nights prior to each experimental session. Duration and quality of participants' sleep preceding experimental sessions were assessed with a three-day sleep diary (results are summarized in Table S1, see online supplement). Twenty-four hours prior to the onset of each experimental session, subjects wore a sensor (Actiheart; Cambridge Neurotechnology, Cambridge, United Kingdom) on their chests to measure heart rate. Heart rate data obtained with the Actiheart device were collected in 15-s epochs. By utilizing this data, the validity of participants' sleep diary reports was confirmed (see Tables S2 and S3 in the online supplement).

All participants signed written informed consent, and the study was approved by the Ethical Committee of Uppsala.

2.2. Experimental procedure

All participants partook in two conditions: reading the printed book titled "*The Magicians*" vs. reading the same book as an e-book on a LED-tablet (ASUS Transformer Pad TF700). Our study employed a within-subject, randomized crossover design, in which each experimental condition was separated by at least six days (see Fig. 1 for the experimental scheme). Participants read the same novel during both conditions, ie, in the second experimental session they continued reading in the book from where they left off at the end of the first reading intervention. Experimental sessions for the female subjects were not scheduled during their respective menstruation phases.

On experimental days, participants arrived at 14:30 and stayed in our sleep laboratory until ~09:00 the next day. Experimental rooms were not equipped with windows, ie, room light conditions were kept constant for 6.5 hours prior to reading intervention (~569 lux measured at the horizontal plane at the desk where participants were mainly seated during this time; see Fig. 2 for the light spectrum).

A light dinner was served at 18:00. The polysomnography (PSG) recording equipment was applied to the participants after the dinner and the PSG hook-up was finished before 20:00. At ~21:00, the 2-h reading intervention was started. To ensure compliance, an experimenter stayed in the experimental room but remained quiet. During each book reading condition (ie, tablet reading or physical book reading), ceiling lights were turned off and only a small reading lamp was turned on at the desk where subjects were sitting to read. The brightness of the tablet screen was set to highest level. Lux levels were measured using a lux meter (Hagner E4-X Digital luxmeter, B.Hagner AB, Solna, Sweden) at the right eye for each participant before starting each intervention session. Measured lux levels were (mean ± SD) 67.3 ± 49.9 in the physical book reading condition and 102.1 ± 41.4 in the tablet reading condition (P = 0.045, Wilcoxon signed ranks test). Light spectra measured by an optical spectrum analyzer (SI-OSMA Optical spectrum analyzer, equipped with a Jarrel Ash monochromator JA-150 and a Princeton Instrument detector: Eiry1024-SI-IRY 1024/L) for both conditions are illustrated in Fig. 3. The measured color temperature was 2674 K in the physical book reading condition and 7718 K in the tablet reading condition, respectively.

Saliva to assay melatonin (sampling procedure and assay descriptions, see ***section 2.3***) was collected every 30 minutes [ie, 21:00 (=around onset of book reading interventions), +30 min, +60 min,

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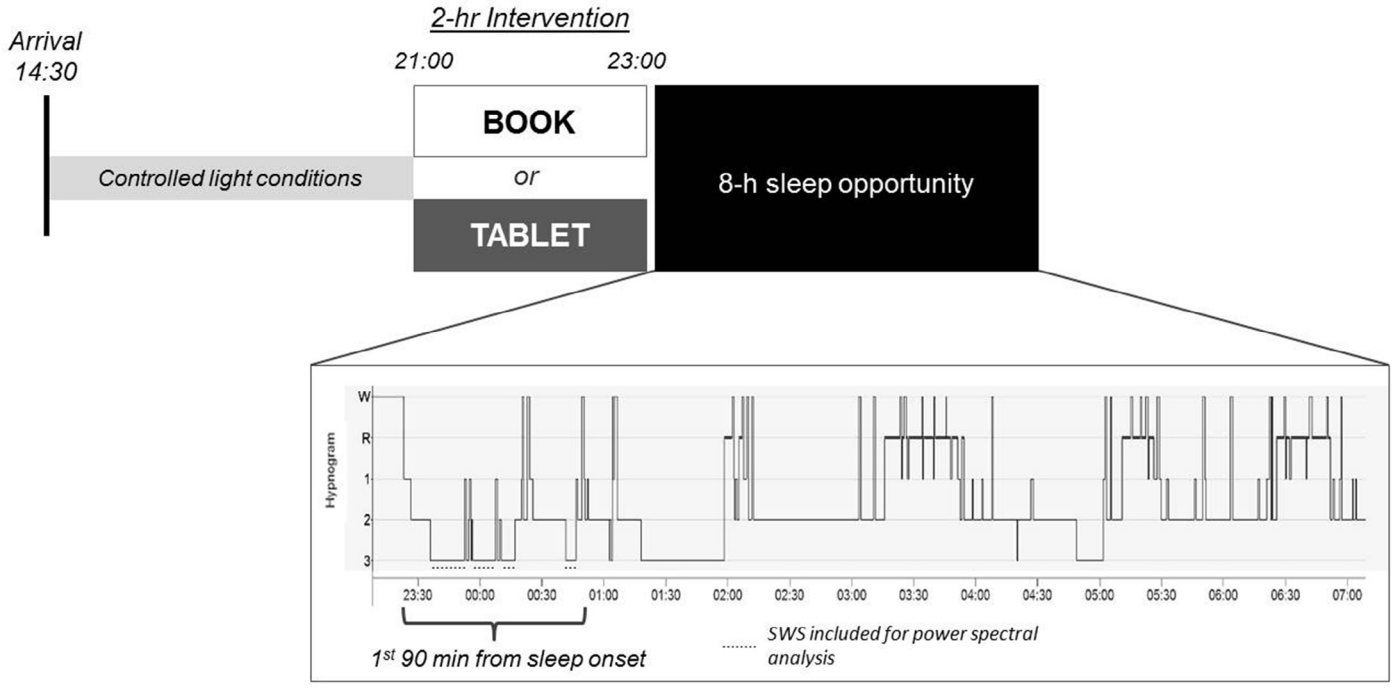

Fig. 1. Schematics over the study design. Participants partook in two conditions: physical book reading vs. tablet reading. Upon arrival at our sleep laboratory (14:30), participants had been kept under constant bright light conditions (~569 lux) over 6.5 hours until the evening reading intervention was started. In one experimental condition, participants read the novel titled "*The Magicians*" as a physical book. In the other experimental condition, they read the same book on a self-luminous tablet set to full brightness (color temperature, physical book vs. tablet: 2674 K vs. 7781 K). During each reading intervention, only a small reading lamp was turned on. After the end of each reading intervention, participants could sleep from 23:15 to 7:15 the next day. Sleep was assessed by polysomnography. Slow-wave sleep (SWS) occurring during the first 90 minutes from sleep onset was used for electroencephalographic power spectral density analysis (symbolized by the hypnogram).

+90 min, +120 min]. Concomitantly, subjects' sleepiness was assessed by the Karolinska Sleepiness Scale (KSS) [24]. Immediately after the end of the reading intervention (ie. ~23:00), participants rated their arousal, as well as answered questions in relation to how much they liked reading the book, how difficult it was, how engaged they were in reading the book, how bored they had been, and how excited and/or upset they felt when reading the book (on 100-mm visual analogue scales). Lights were off at night from ~23:15 to ~07:15 in both conditions (description of how sleep was assessed, see ***section 2.4***). The next morning, subjects were asked to rate their sleepiness (KKS) at ~ 07:15 (time 0), +15, +30, +45, and +60 minutes.

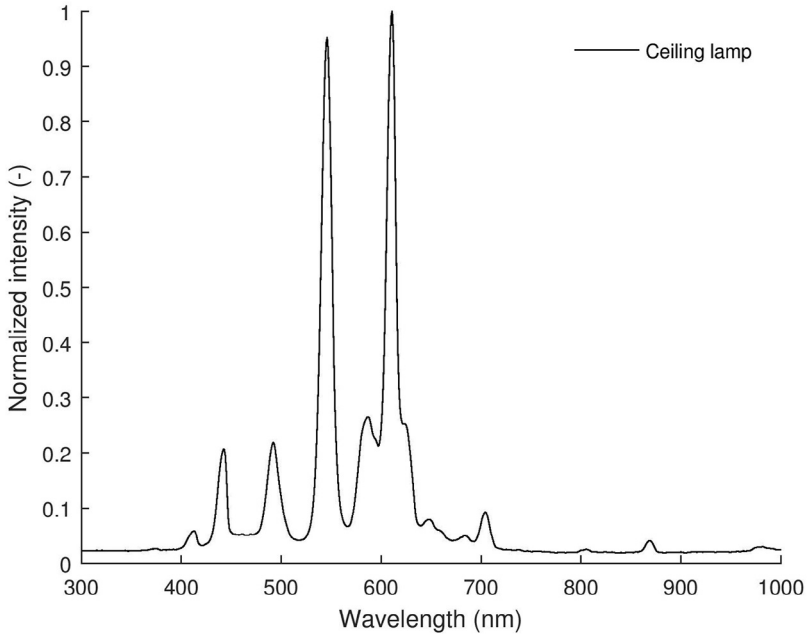

Fig. 2. Light spectrum for the ceiling light in the sleep laboratory until the start of the intervention. Measured peak spectral intensity was 611 nm and the color temperature was 3149 K.

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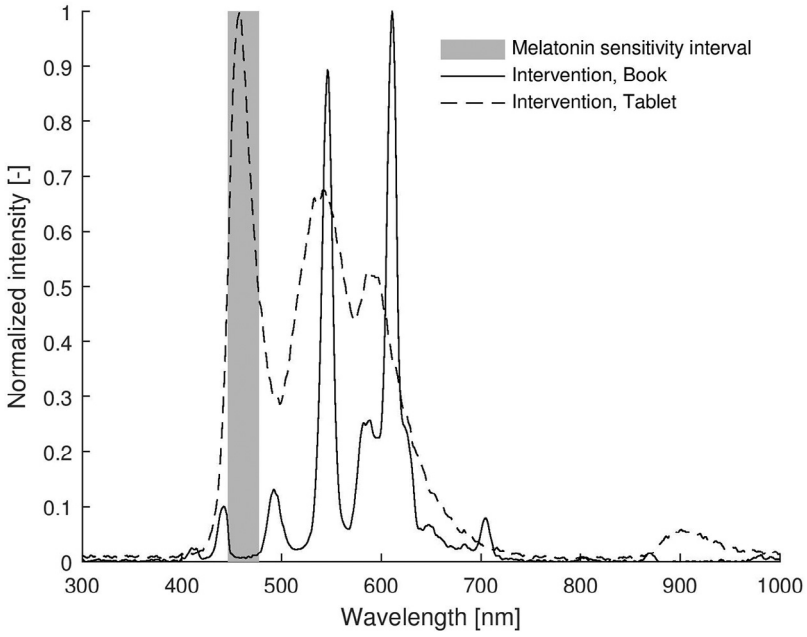

Fig. 3. Measured light spectrum during evening reading interventions. Measured peak spectral intensity was 611 nm during the physical book reading condition (solid line) and 458 nm during the tablet reading condition (dashed line). The color temperature was 2674 K for the physical book reading condition and 7718 K for the tablet reading condition. Thus, participants were exposed to more bluish light when reading the novel on the tablet vs. reading the novel as a physical book. Accordingly, the area under the curve within the interval 446–477 nm (ie, part of the light spectrum that has been shown to halt melatonin production to the greatest extent, see also Ref. [23]) was 24.5-fold larger in the tablet reading condition than in the physical book reading condition (expressed as percentage of the whole light spectrum from 300 to 1000 nm, 21.85% vs. 0.89%).

2.3. Melatonin

The sampling of saliva for melatonin determination was performed using SaliCaps and straws (IBL International GmbH, Hamburg, Germany). Samples were stored at –80 °C until analysis. Saliva melatonin concentrations were determined by a commercially available immunoassay with luminescence detection (LIA, IBL-International, Hamburg, Germany). Intra- and inter-assay coefficients of variance for this assay concerning saliva measurement have been shown to be below 10%. To account for inter-individual differences, saliva melatonin levels were normalized by dividing all values by the mean for each participant and condition. Saliva melatonin was measured in a subsample, N = 10.

2.4. Sleep

EEG was recorded from five channels (F3, F4, Cz, O1, and O2); in addition to left and right electrooculogram (EOG) and chin electromyogram (EMG). The EEG and EOG channels were referenced to its contralateral mastoid electrode (A1 and A2). Recording was done using an ambulatory EMBLA system (Embla A10 recorders; Flaga hf, Reykjavik, Iceland); sampling frequency was set to 200 Hz. Sleep stages were visually scored in Polyman (version 1.15.3.1065) based on electrodes F3 and F4 (0.3–30 Hz bandpass filtered) for 30-second epochs. Sleep stages were defined according to AASM criteria [25]. For each night, SOL (with reference to minutes from lights off at ~23:15 until sleep onset, defined as the first of three consecutive 30-second epochs of sleep), total sleep time (TST), and latency of SWS (first epoch of SWS) with reference to sleep onset were determined. Time in sleep stages [sleep stage 1 (N1), sleep stage 2 (N2), SWS, and REM sleep] were expressed as a percentage of TST and for the first 90 minutes after sleep onset. Time awake after sleep onset was expressed as a percentage of the time interval between sleep onset and lights on at ~7:15 (%WASO).

Two hours of evening exposure to blue-enriched light has been found to impact occipital SWA during non-REM sleep [26]; thus, we also investigated if evening tablet use would alter SWA of early SWS. To this aim, a Fast Fourier Transform (10% Hanning window) was applied to the SWS occurring during the first 90 minutes from sleep onset, after the signals had been band-pass filtered (High-pass: 0.3 Hz, Low-pass: 30 Hz, Notch: 50 Hz), artifacts rejected (manually, for 30-second epochs), and signals had been segmented into eight-second epochs with 50% overlap. Following the Fast Fourier Transform, the power density (μV^2/Hz) was averaged across epochs from which the sum power density was exported for the frequency bands of interest: 0.5–1 Hz (slow oscillations), 1–4 Hz (SWA), 4–7 Hz (theta activity), 8–12 Hz (alpha activity), 12–15 Hz (spindle activity), and 15–25 Hz (beta activity), as well as the whole range from 0.5 to 25 Hz. The sum power density for each frequency band and EEG channel were log-transformed before used in the statistical analyses. Two participants could not be included in the power spectral analysis of sleep due to technical issues.

2.5. Statistical analysis

For statistical evaluation, SPSS version 21.0 (SPSS Inc, Chicago, IL) was used. Comparisons between the effects of tablet e-book reading and conventional book reading (ie, reading a printed book) were based on linear mixed models (unless otherwise stated) with the fixed repeated factor "*Condition*" (as well as the factor "*Time*" where appropriate), and fixed covariates "*Gender*" and log-transformed "*Chronotype*". The model also included "*Condition*" by "*Time*" interaction effects, where appropriate. The covariance matrix chosen for each model was tested for best fit using –2 Restricted Log Likelihood. The Restricted Maximum Likelihood method was used. The models used for analyses are summarized in the online supplement (Table S4).

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Log transformation (as well as normalization of melatonin levels) was used for non-normally distributed variables in order to approach normality. Overall, two-tailed p-values less than 0.05 were considered significant.

3. Results

3.1. Saliva melatonin concentrations and sleepiness

Fig. 4 summarizes the effects of evening tablet reading vs. physical book reading on evening melatonin levels and subjective sleepiness. According to the typical circadian rhythmicity of melatonin release, saliva melatonin levels as well as sleepiness increased as the evening progressed (*Time* effect, normalized melatonin levels, P = 0.00007; *Time* effect evening sleepiness, P = 0.000002), but both remained unaffected by evening tablet reading.

3.2. Subjective arousal

Subjective ratings of arousal and other feelings (including questions such as how much they liked reading the book, how difficult it was, how engaged they were in reading the book, how bored they had been, and how exciting and upset they felt when reading the book) did not differ between the two book reading conditions (P ≥ 0.08 for all comparisons).

3.3. Sleep onset latency and sleep composition

Fig. 5 and Table S5 (see online supplement) summarize PSG sleep parameters for the two book reading conditions. Overall, evening tablet use did not affect sleep characteristics such as sleep onset latency, sleep duration, or time spent in the different sleep stages (both for the whole night and for the first 90 minutes from sleep onset, which is the time-frame from which the SWS used in the power spectral analysis was derived). Also, time from sleep onset until first epoch of SWS (SWS latency) was unaffected.

3.4. Power spectral density during SWS

The power spectral density during SWS at sites F3, F4, Cz, O1, and O2 did not differ between the tablet reading and physical book reading conditions (Table 1) for any frequency band (slow oscillations 0.5–1 Hz, SWA 1–4 Hz, theta 4–7 Hz, alpha 8–12 Hz, spindle 12–15 Hz, beta 15–25 Hz).

3.5. Subjective ratings of sleep and morning sleepiness

In the morning following evening tablet reading vs. physical book reading, participants' ratings concerning the time it took to fall asleep, how well they had slept, and how well rested they felt did not differ between reading conditions (P ≥ 0.13 for all comparisons). Moreover, morning sleepiness remained unaffected by evening tablet reading (Fig. 6).

4. Discussion

Blue light emitted by technical devices has been proposed to represent one of the mechanisms through which evening use of eg, tablet computers can lead to sleep disturbances in humans. Against this background, the present study involving 14 young adults sought to investigate if evening reading on a self-luminous tablet would alter sleepiness, saliva levels of the sleep-promoting hormone melatonin, sleep onset latency (SOL), sleep composition, as well as electroencephalographic power spectral density during early slow-wave sleep (SWS).

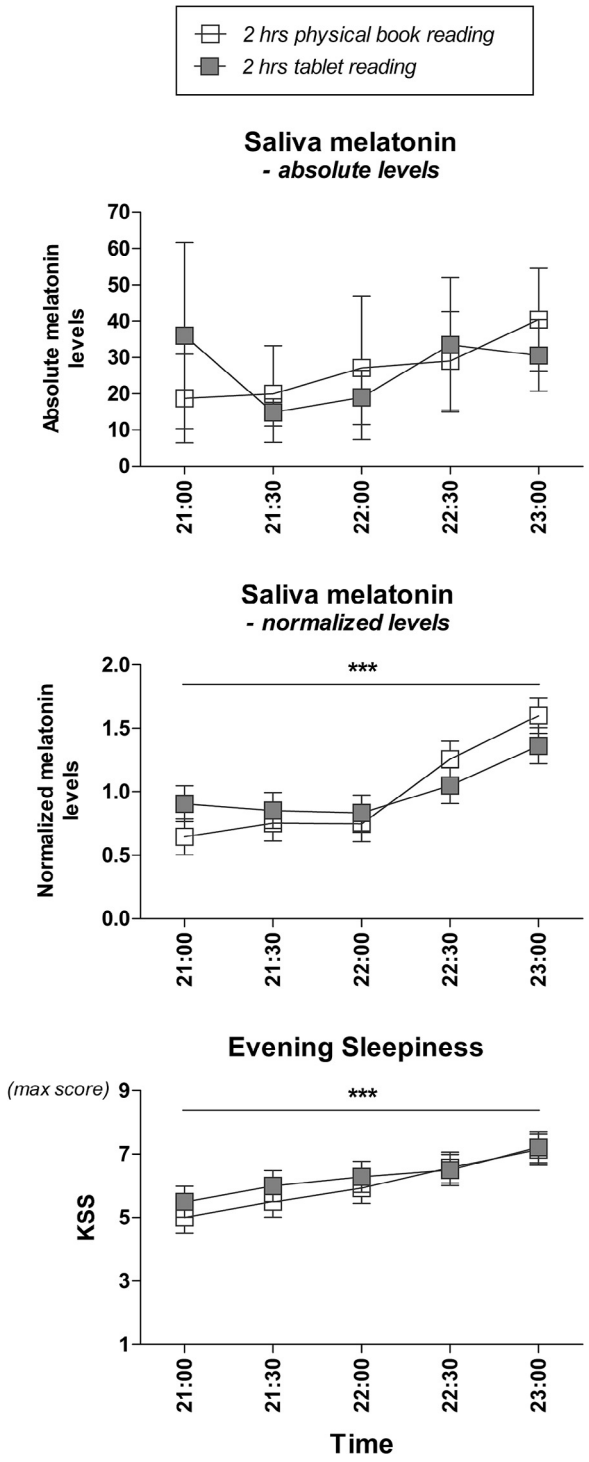

Fig. 4. Saliva levels of melatonin and subjective sleepiness during the evening reading conditions. *Upper panel*: Raw data (mean ± SEM) for saliva melatonin concentrations (N = 10); absolute levels were not used for statistical analysis. *Middle panel*: Normalized saliva melatonin concentrations (N = 10). *Bottom panel*: Sleepiness during the evening (N = 14). Estimated means ± SEM are shown, covarying for gender and chronotype. For melatonin, normalized values were entered into the statistical analysis to account for inter-individual differences. *Abbreviations*: KSS = Karolinska Sleepiness Scale. ***P < 0.001 for the main effect of time. There was no interaction between reading conditions and time (P ≥ 0.28 for all comparisons).

Our main finding was that evening use of a self-luminous tablet (set to full brightness) for two hours did not affect sleepiness and saliva melatonin levels before sleep, nor did it change time to fall asleep or subsequent sleep. At first glance, these findings appear

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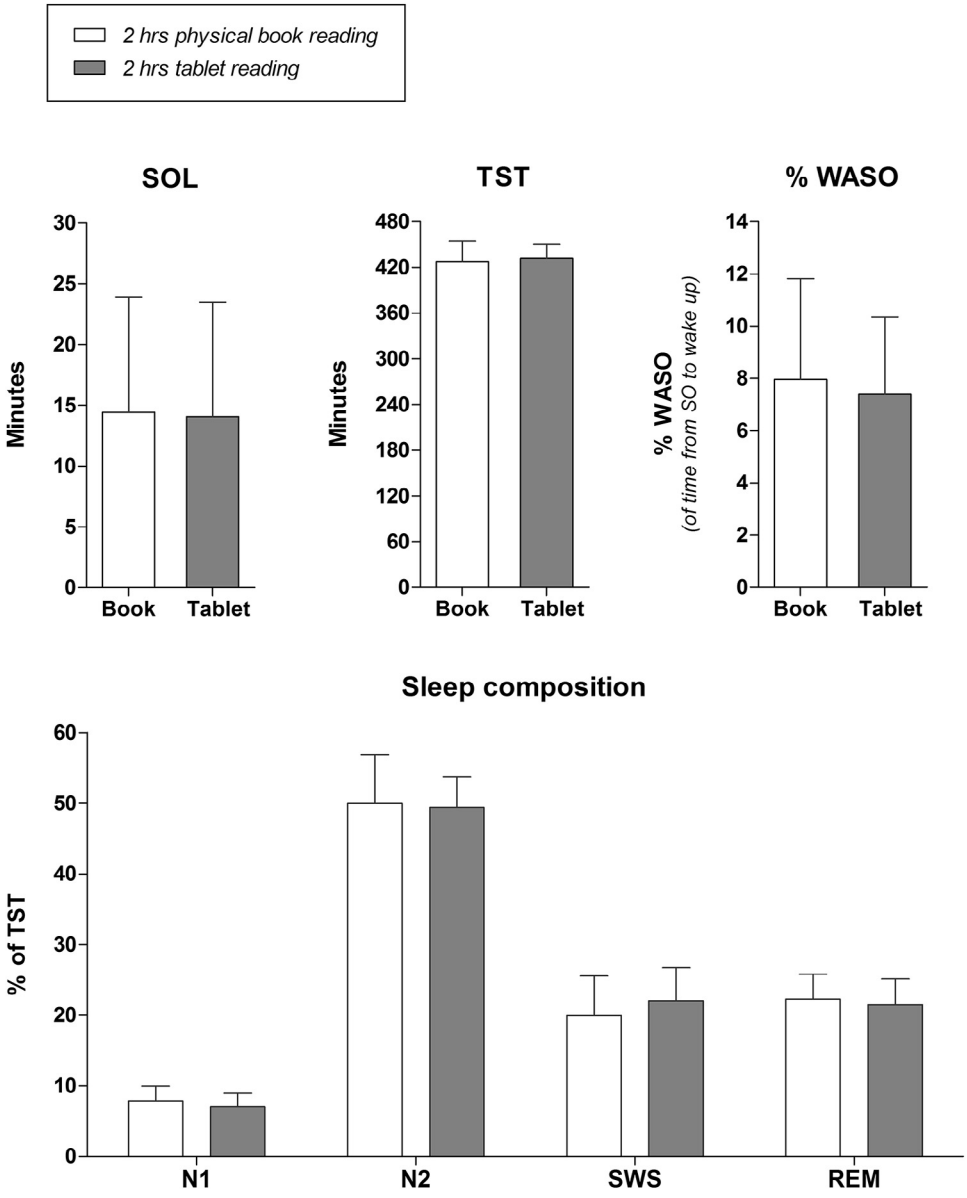

Fig. 5. Effects of evening tablet reading on sleep onset latency and sleep composition. Means ± SD. *Abbreviations*: SOL = Sleep onset latency; TST = Total sleep time; WASO = Wake after sleep onset; N1 = Stage 1 sleep; N2 = Stage 2 sleep; SWS = Slow-wave sleep; REM = Rapid eye-movement sleep. $P \geq 0.08$ for all main effects of condition (ie, book vs. tablet). Data were available for N = 14.

inconsistent with results from previous studies. For instance, in one study involving 12 young adults (six females), it was demonstrated that reading on an e-reader between 18:00 and 22:00 reduced evening melatonin secretion and evening sleepiness, increased SOL, and decreased time in REM sleep [16]. In another study involving 16 young adults (12 females), it was further shown that evening reading on an iPad for about 30 minutes reduced early night slow-wave activity (SWA); however, in this study, SOL and time in different sleep stages remained unaltered [20]. One explanation for the discrepancy between studies could relate to differences in the light exposure prior to evening tablet use. Bright light exposure during daytime over one to several days – similar to that employed in the present study – has previously been shown to attenuate the suppressive properties of evening short-wavelength-enriched light on evening melatonin levels [27–30].

In contrast to the present study, in which participants were exposed to two hours of evening tablet reading, the effects of evening tablet use on sleep parameters in a previous study were observed after five days of tablet use scheduled every evening between 18:00 and 22:00 [16]. This could suggest that the duration, timing, and repetition of evening light stimulus may also determine the extent by which the light from technical screen-based devices alters evening melatonin production and subsequent sleep. In this context however, it must be mentioned that there is also controversial evidence with respect to the dose–response hypothesis since a recent study [20] found that only 30 minutes of tablet use lowered SWA during early sleep, with no effects on SOL nor time in different sleep stages. Daytime light conditions and use of technological devices prior to the evening tablet intervention were however not controlled for in this in-home study, nor was the type of light used in the printed book condition considered.

5. Limitations

First, it must be kept in mind that the sample size of our experiment and that of other studies exploring the effects of evening tablet

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Table 1
Power spectral density during slow-wave sleep in the first 90 minutes from sleep onset.

Electrode site	Frequency band (Hz)	Book reading (log μV^2/Hz)	Tablet reading (log μV^2/Hz)	P
F3	0.5–1	3.19 ± 0.23	3.20 ± 0.28	0.77
	1–4	3.55 ± 0.25	3.55 ± 0.20	0.77
	4–7	2.36 ± 0.17	2.37 ± 0.13	0.58
	8–12	1.91 ± 0.34	1.93 ± 0.30	0.54
	12–15	1.41 ± 0.29	1.44 ± 0.27	0.36
	15–25	1.12 ± 0.16	1.17 ± 0.13	0.10
F4	0.5–1	3.23 ± 0.23	3.23 ± 0.28	0.96
	1–4	3.55 ± 0.25	3.55 ± 0.19	0.89
	4–7	2.37 ± 0.17	2.38 ± 0.13	0.59
	8–12	1.92 ± 0.36	1.94 ± 0.30	0.39
	12–15	1.41 ± 0.27	1.45 ± 0.24	0.25
	15–25	1.23 ± 0.15	1.26 ± 0.17	0.39
Cz	0.5–1	3.25 ± 0.25	3.24 ± 0.30	0.86
	1–4	3.50 ± 0.21	3.49 ± 0.19	0.62
	4–7	2.45 ± 0.12	2.45 ± 0.12	0.85
	8–12	1.91 ± 0.24	1.91 ± 0.23	0.93
	12–15	1.71 ± 0.19	1.73 ± 0.20	0.47
	15–25	1.34 ± 0.13	1.37 ± 0.12	0.29
O1	0.5–1	2.85 ± 0.21	2.84 ± 0.29	0.86
	1–4	3.00 ± 0.24	2.98 ± 0.18	0.58
	4–7	2.18 ± 0.21	2.20 ± 0.13	0.63
	8–12	1.60 ± 0.25	1.60 ± 0.16	0.85
	12–15	1.27 ± 0.29	1.25 ± 0.18	0.74
	15–25	1.08 ± 0.18	1.10 ± 0.16	0.50
O2	0.5–1	2.95 ± 0.25	2.92 ± 0.32	0.64
	1–4	3.05 ± 0.19	3.02 ± 0.19	0.43
	4–7	2.24 ± 0.11	2.22 ± 0.10	0.46
	8–12	1.66 ± 0.18	1.65 ± 0.12	0.74
	12–15	1.29 ± 0.20	1.30 ± 0.14	0.97
	15–25	1.15 ± 0.17	1.19 ± 0.16	0.47

Abbreviation: Hz band, frequency band.
Data represent log transformed means ± SD; P-values are for main effects of *condition* from linear mixed models.
N = 12 (N = 11 for electrode O2).

light exposure on melatonin and sleep were relatively small (range: 12–16 subjects; see also Ref. [16] and Ref. [20]). This may have limited the statistical power to detect the full range of possible effects of tablet computer use on various sleep parameters, and may also explain discrepant results across studies. Second, in the present study, subjects were exposed to bright light conditions of about 569 lux over 6.5 hours. Normally, indoor lighting typically varies between 100 lux and 250 lux. Third, we did not measure participants' light exposure prior to the onset of our experimental session (ie, prior to 14:30 on the experimental day). Fourth, our participants were only exposed to the tablet for two hours; thus, we could only examine potential acute effects from evening tablet light exposure. Fifth, our study sample was too small to reliably explore for instance possible gender differences. Further, other factors that may determine the effects of evening tablet light on melatonin and sleep were not considered in the present study (eg, age). Finally, it must be borne in mind that reading is generally considered to be a cognitively demanding task. For instance, reading a novel has been shown to significantly increase brain connectivity [31]. Thus, it could be speculated that increases in neural energy expenditure associated with evening reading may contribute to greater homeostatic sleep pressure, which may have hampered our ability to detect differences in sleep parameters between the tablet reading and physical book reading conditions. A recent study involving young children has for instance demonstrated that reading at bedtime is associated with improved sleep, as indicated by longer total nocturnal sleep duration [32].

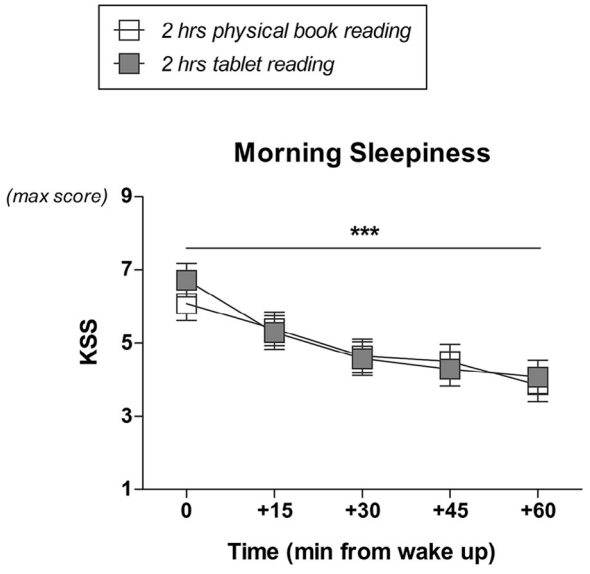

Fig. 6. Subjective sleepiness (measured by KSS) in the morning following evening reading conditions (x-axis is time in min from wake up). Estimated means ± SEM, covarying for gender and chronotype. Abbreviations: KSS = Karolinska Sleepiness Scale. ***P < 0.001 for the main effect of time. There was no interaction between condition and time (P = 0.14). Data were available for N = 14.

6. Conclusions

The extent by which light from evening tablet use may influence nocturnal sleep in humans appears to depend on various factors, such as daytime photic preload and duration of evening tablet use. Future studies with larger sample sizes are needed to determine if natural and artificial alterations to daytime light exposure (eg, as a result of seasonal changes or light manipulations at working places) impact to which extent sleep is influenced by evening blue light emitting devices and could potentially counteract related sleep disturbances.

Conflict of interest

The authors declare no conflicts of interest.
The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2016.06.016.

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Appendix: Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.sleep.2016.06.016.

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