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Blue Blocker Glasses as a Countermeasure for Alerting Effects of Evening Light-Emitting Diode Screen Exposure in Male Teenagers

Stéphanie van der Lely, M.Sc. [a], Silvia Frey, Ph.D. [a], Corrado Garbazza, M.D. [a], Anna Wirz-Justice, Ph.D. [a], Oskar G. Jenni, M.D. [b], Roland Steiner, B.Sc. [c], Stefan Wolf, Ph.D. [d], Christian Cajochen, Ph.D. [a], Vivien Bromundt, Ph.D. [a,*,1], and Christina Schmidt, Ph.D. [a,1]

[a] *Centre for Chronobiology, Psychiatric Hospital of the University of Basel, Basel, Switzerland*
[b] *Child Development Center, University Children's Hospital Zürich, Zürich, Switzerland*
[c] *Department of Physics, University of Basel, Basel, Switzerland*
[d] *Department of Mechanical Engineering, Lighting Engineering Group, Ilmenau University of Technology, Ilmenau, Germany*

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A B S T R A C T

Purpose: Adolescents prefer sleep and wake times that are considerably delayed compared with younger children or adults. Concomitantly, multimedia use in the evening is prevalent among teenagers and involves light exposure, particularly in the blue-wavelength range to which the biological clock and its associated arousal promotion system is the most sensitive. We investigated whether the use of blue light–blocking glasses (BB) during the evening, while sitting in front of a light-emitting diode (LED) computer screen, favors sleep initiating mechanisms at the subjective, cognitive, and physiological level.

Methods: The ambulatory part of the study comprised 2 weeks during which the sleep–wake cycle, evening light exposure, and multimedia screen use were monitored in thirteen 15- to 17-year-old healthy male volunteers. BB or clear lenses as control glasses were worn in a counterbalanced crossover design for 1 week each, during the evening hours while using LED screens. Afterward, participants entered the laboratory and underwent an evening blue light–enriched LED screen exposure during which they wore the same glasses as during the preceding week. Salivary melatonin, subjective sleepiness, and vigilant attention were regularly assayed, and subsequent sleep was recorded by polysomnography.

Results: Compared with clear lenses, BB significantly attenuated LED-induced melatonin suppression in the evening and decreased vigilant attention and subjective alertness before bedtime. Visually scored sleep stages and behavioral measures collected the morning after were not modified.

Conclusions: BB glasses may be useful in adolescents as a countermeasure for alerting effects induced by light exposure through LED screens and therefore potentially impede the negative effects modern lighting imposes on circadian physiology in the evening.

IMPLICATIONS AND CONTRIBUTION

Computer screen lighting can impact on sleep–wake regulation, a topic highly relevant for health and well-being in adolescents. Blue light–blocking glasses might be a useful countermeasure of the wake-promoting effects induced by light-emitting diode screen exposure before sleep onset.

Poor sleep quality, insufficient sleep duration, and daytime sleepiness are prevalent among adolescents [1]. These problems are associated with emotional instability, impaired daytime functioning, and poor school performance [2]. Adolescence is characterized by a prominent developmental shift of the internal

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* Address correspondence to: Vivien Bromundt, Ph.D., Centre for Chronobiology, Psychiatric Hospital of the University of Basel, Wilhelm Klein-Strasse 27, CH-4012 Basel, Switzerland.
E-mail address: vivien.bromundt@upkbs.ch (V. Bromundt).

[1] These authors contributed equally to the work.

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clock located in the suprachiasmatic nuclei of the hypothalamus toward eveningness. Late chronotypes (delayed sleep and wake time preferences) are predominant [3], with more mature adolescents having later circadian phases [4]. Accordingly, delayed sleep phase syndrome, characterized by a chronic or recurrent inability to fall asleep and wake up at socially conventional times, presents the highest prevalence (.5%–16%) in adolescents [5]. Beside the circadian system, sleep homeostasis also undergoes developmental changes, with a slower buildup rate for sleep need with increasing time spent awake in more mature teenagers [6]. Teenagers are thus ready to fall asleep only late at night, but they have to be early at school or work, which may consequently lead to accumulated sleep loss, daytime sleepiness, and impaired cognitive daytime functioning [7]. External influences, such as evening work, social opportunities, and reduced parental influences on bedtimes, may even potentiate such delayed and short sleep epochs in young people [8].

A further potential contributing factor to poor sleep quality in adolescents is the use of multimedia screens in the evening hours for entertainment, identity formation, and socialization [9]. In-bed computer and phone usage before sleep has been positively associated with insomnia and negatively with morningness [10]. Because light is the most important zeitgeber (i.e., synchronizer) for the circadian timing system, its emission by computer or multimedia screens (smartphones, tablets, and so forth) impacts on the internal clock and thus on circadian physiology [11], probably also including sleep–wake regulation. Morning light phase advances circadian rhythms, whereas light in the evening induces circadian phase delays [12]. Individuals with delayed sleep phase seem to be even more sensitive to evening light than earlier chronotypes [13].

The impact of light on the circadian timing system is classically measured by suppression of the “darkness hormone” melatonin, a key circadian phase marker secreted only during the night [14]. Light also enhances alertness and cognitive performance [15]. These responses are mediated by a subset of retinal ganglion cells containing the photopigment melanopsin, most sensitive to wavelengths within the blue light spectrum around 480 nm [16,17], which transmit light signals via the retinohypothalamic tract directly to the suprachiasmatic nuclei [18]. Accordingly, blue light has been shown to act most strongly on circadian physiology, alertness, and cognitive performance [11].

Light-emitting diode (LED) screens present a high proportion of short-wavelength light. The screen light of tablets can suppress melatonin [19]. A 5-hour LED screen exposure in the evening not only suppressed melatonin secretion but also increased subjective and objective alertness in young adults [11]. Orange-tinted blue light–blocking glasses (BB)—so-called blue blockers—can be used to counter such light effects because they filter out the short wavelengths in the blue range portion of the spectrum. BB glasses prevented light-induced melatonin suppression and alerting effects in young adults [20,21]. Wearing BBs in the evening significantly improved subjective sleep quality after a continuous 2-week application [22]. In contrast, blocking short-wavelength light in the morning with BB glasses delayed circadian phase in young adults [23,24]. However, the impact of BB glasses as a potential countermeasure in adolescents’ sleep and waking behavior has only begun to be investigated, particularly with objective measures, although this population appears to be at particular risk of further delaying sleep timing secondary to evening light exposure.

We therefore investigated in a group of male teenagers, used to sitting in front of LED screens for several hours daily and tending toward extreme evening types, whether wearing BB glasses could modify melatonin secretion, alertness, cognitive performance, and sleep (monitored by electroencephalography [EEG]) compared with wearing clear lenses (CL) as a control condition. All these variables have previously been shown to be affected by prior light exposure [15].

Methods

Study participants

Healthy, male, high-school students between 15 and 17 years old were recruited for the study in the Basel (Switzerland) area through oral presentations in schools, Web postings, and advertisements. Potential participants underwent a screening survey about their general health, sleep, and well-being (see Supplementary Data). Thirteen study volunteers (mean ± standard deviation, 16.46 ± .66 years old) were finally included in the study. Supplementary Table 1 summarizes their screening survey data.

All participants and their parents were informed about the study details and provided written informed consent before the study onset. The study was approved by the local ethics committee (Ethikkommission beider Basel, Basel, Switzerland) and conformed to the Declaration of Helsinki.

Study protocol

The study protocol lasted 16 days and was organized in two study parts in a balanced crossover design separated by an intervening period of at least 1 week to maximally 5 weeks (2.00 ± 1.29 weeks). Each study part comprised a 15.5-hour stay in the laboratory and a preceding ambulatory week. The participants were asked to maintain their usual sleep–wake rhythm but were not permitted to go out in the evenings or nap during the day for 3 days before the in-laboratory part. Caffeinated drinks were not allowed, and the participants were asked to refrain from drinking more than three glasses of alcohol per week.

Ambulatory part

Glasses/Luxblick. During the ambulatory week preceding the laboratory night, participants wore orange-tinted BB glasses, so-called blue blockers (Chron-optic Inc., Quebec City, Quebec, Canada), or glasses of equal design with CL as control condition (Chron-optic Inc.) from 18:00 hours until sleep onset (for as much time as possible) in a counterbalanced crossover design. The light transmittance spectra of the two glasses are depicted in Supplementary Figure 1. Besides blocking the blue light portion of the spectrum, reduced light transmittance resulted also in lower light intensity levels in BB (30% transmittance) compared with CL (92% transmittance).

Additionally, to control for light exposure, a small low-weight device called “Luxblick” [25] was fixed on the glasses frame between the eyes to measure vertical illuminance and irradiance at second intervals (see Supplementary Data for details). Participants also kept a diary indicating when and for how long they wore the glasses, and how much time they spent in front of a LED/non-LED screen. Compliance of wearing the glasses was

measured by using the subjects' logs and by double checking with the Luxblick data.

Actimetry and sleep logs. The participant's rest–activity cycle during the week before the study nights was measured via actimetry (Actiwatch L; Cambridge Neurotechnology Ltd., Cambridge, United Kingdom), worn on the wrist of the nondominant hand (see Supplementary Data for details). Additionally, all participants completed a daily sleep–wake log indicating sleep times and time spent at school.

Laboratory part

At the end of each ambulatory week, participants reported to the laboratory of the Centre for Chronobiology for the in-laboratory part of the study (see Figure 1 for an overview). The volunteers entered the laboratory 5.5 hours before scheduled sleep time. The precise schedule of each session was individually calculated according to the subject's habitual bedtime based on the average timing of the sleep midpoints derived from the actimetry data during the preceding 5 days. The first 2 hours of the protocol were spent sitting in dim light (<8 lux at eye level), followed by dark adaptation for half an hour and then 3 hours sitting in front of a LED back-lit computer screen (see Supplementary Data for details of the screen) wearing either BB or CL glasses. Light was turned off in the laboratory, but the LED screen was set to a white background and maximal brightness. During the 5.5-hour session, the participants were asked to complete several cognitive tests, fill in scales, and provide saliva samples (for details see the following). After the 3 hours of LED screen exposure, participants went to sleep and polysomnographic recordings were conducted (see section polysomnography) during an 8-hour sleep epoch. In the morning, the same scales and tests were applied and saliva samples were taken as in the preceding evening under dim light (<8 lux).

Subjective assessment of sleep quality, sleepiness, and visual comfort. Participants rated their current sleepiness level on the Karolinska Sleepiness Scale [26] administered every 30 minutes during wakefulness. A visual comfort scale was filled in once, when sitting in front of the LED screen along with a 100-mm scale for visual well-being and comfort, brightness, and glare while wearing BB or CL glasses. In the morning after wake up, subjective sleep quality was assessed by two items of the Leeds Sleep Evaluation Questionnaire (Cronbach's alpha = .636; [27]).

Salivary melatonin. In parallel with the Karolinska Sleepiness Scale, study volunteers provided saliva samples every 30 minutes during scheduled wakefulness using Salivettes (Sarstedt AG, Sevelen, Switzerland). A direct double antibody radioimmunoassay was used for the melatonin assay (see Supplementary Data for details). The dim-light melatonin onset (DLMO) was used as a phase marker of the circadian clock. It was calculated with the objective hockey-stick method [28]. The phase angle was calculated as sleep onset minus the DLMO.

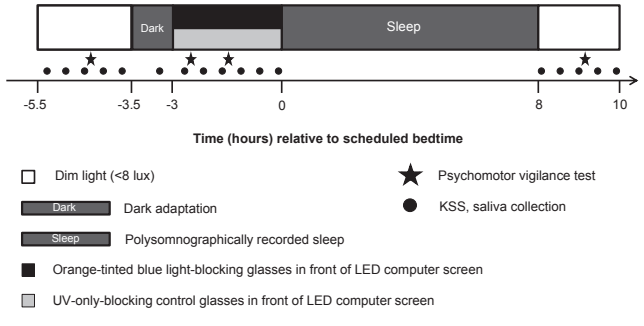

Figure 1. In-laboratory study protocol. KSS = Karolinska Sleepiness Scale.

Cognitive performance. Sustained attention performance was assessed using a psychomotor vigilance test ([29]; see Supplementary Data for details). This test was performed four times per study night; the first time in the evening during the dim-light condition, afterward twice during the LED screen condition with a break of 1 hour, and the fourth time in the morning again in dim light. Data analyses focused on reaction times (RTs) and lapses of attention (RT > 500 ms).

Polysomnography. Sleep and wakefulness was recorded using the Vitaport digital ambulatory sleep recorder system (Vitaport-3 digital recorder; TEMEC Instruments, Kerkrade, The Netherlands; see Supplementary Data for details). Six electroencephalographic leads (Fz, Cz, C3, C4, Pz, Oz) as well as submental electromyographic, electrooculographic, and electrocardiographic signals were recorded. Polysomnographic data were scored visually on a 20-second epoch basis according to standard criteria [30].

Statistical analysis. Data were collected from 13 subjects. The melatonin data of one subject were excluded from analysis because the values deviated more than two standard deviations from the mean of all subjects, and EEG data from two subjects were excluded because of very low quality EEG signals. For all analyses, the statistical package SAS (version 9.3; SAS Institute Inc., Cary, NC) was used. A mixed-model analysis of variance for repeated measures (PROC MIXED) with factors "glasses" (i.e., BB vs. CL) and "sampling time" (i.e., four vs. 17 measurements for cognitive tests and subjective scales, respectively) was applied. For the analysis of wrist-activity data, the factors "glasses" (i.e., BB vs. CL), "time of day" (i.e., time of one hourly binned averaged activity data), and "day type" (i.e., weekdays vs. weekend days) were used. p values were based on corrected degrees of freedom by Kenward and Roger [31]. The alpha criterion was set at a significance level of $p = .05$. Furthermore, an intraclass correlation coefficient was calculated for actimetrically derived sleep parameters.

Results

Ambulatory actimetry

Twenty-four–hour activity profiles preceding the laboratory nights were not significantly different between the BB and CL conditions (n = 13; $F(1,564) = .54$; $p = .463$), but an expected significant difference for the factor "time of day" ($F(23,564) = 34.23$; $p < .001$) was found, and there was no significant interaction "glasses × time of day" ($F(23,564) = .45$; $p = .988$). Moreover, none of the actimetry-derived sleep parameters showed significant differences between the BB and CL conditions; however, a significant main effect of factor "day type" was found, indicating, for example, later bedtimes and get up times and longer sleep duration at the weekends ($p < .05$; for more details see Supplementary Table 2).

Ambulatory Luxblick measures

Based on participant's logs and confirmed by the Luxblick measurement, the BB glasses were worn on average for 03:08 hours ± 01:11 hours during the evenings and the CL glasses for 03:24 hours ± 00:58 hours (n = 13; $F(1,11.8) = -.67$; $p = .430$). Light intensity in the evenings at home did not significantly differ between the two conditions (BB: 34.17 ± 25.50 lux; CL: 32.16 ± 17.49 lux; $F(1,11.8) = .05$; $p = .823$). Furthermore, the reported hours spent at school and in front of an LED screen did not significantly differ between the two conditions (n = 13, school: BB, 04:51 hours ± 0:51 hours; CL, 05:15 hours ± 01:04 hours; $F(1,12) = 1.56$; $p = .235$; LED: BB, 03:33 hours ± 01:05 hours; CL, 03:25 hours ± 00:58 hours; $F(1,12) = .04$, $p = .838$).

Laboratory illuminance measures

In dim light, the light intensity did not significantly differ between the two conditions (evening: BB, 6.43 ± .74 lux; CL, 6.58 ± .53 lux; n = 13; $F(1,12) = .63$; $p = .441$; morning: BB, 6.39 ± .56 lux; CL, 6.41 ± .55 lux; $F(1,12) = .01$; $p = .907$), similarly light intensity on the glasses' level during the 3-hour LED screen exposure did not significantly differ between BB (106.14 ± 5.76 lux) and the CL (103.42 ± 6.61 lux; $F(1,12) = 1.75$; $p = .210$).

Visual comfort

Participants perceived the environment through the BB as significantly darker (n = 13; $F(1,12) = 17.70$; $p = .001$) and the light as significantly less glaring ($F(1,12) = 17.66$; $p = .001$) than when they were wearing the CL. All other subjectively rated variables showed no significant differences.

Subjective sleepiness

A significant main effect of factor glasses and sampling time (n = 13; glasses: $F(1,391) = 4.91$; $p = .027$; sampling time: $F(16,391) = 14.34$; $p < .001$), as well as a tendency for the interaction "glasses × sampling time" was observed for subjective sleepiness ($F(16, 391) = 1.61$; $p = .063$; Figure 2). Participants felt significantly sleepier while wearing the BB compared with the CL glasses. With respect to the time course of sleepiness throughout the protocol, participants felt significantly less sleepy at the beginning of the BB protocol (18:00 hours; $p = .032$), whereas at the end of the evening, they felt significantly more sleepy compared with the CL condition (post hoc comparisons; $p \leq .011$). Subjective sleepiness did not significantly differ between the two conditions the following morning.

Melatonin

A significant main effect of glasses (n = 12; $F(1,321) = 7.34$; $p = .007$), sampling time ($F(16,320) = 27.24$; $p < .001$), and an interaction between glasses × sampling time ($F(16,320) = 2.19$; $p = .006$) were detected, such that the evening rise in endogenous melatonin levels was significantly attenuated during the CL condition compared with the BB condition (Figure 3). Significantly higher melatonin levels were measured in the BB condition from 90 minutes to 5 minutes before sleep (four samples; post hoc comparisons; $p \leq .014$).

Neither the DLMO nor the phase angle significantly differed between the conditions (DLMO: 20:43 hours ± 00:51 hours and 20:57 hours ± 01:09 hours for BB and CL, respectively [n = 12; $F(1,11) = .95$; $p = .351$]; phase angle: 03:05 hours ± 00:44 hours and 02:57 hours ± 01:01 hours for BB and CL, respectively; $F(1,11)=.30$, $p=.592$).

Psychomotor vigilance test

The main effect of the factor glasses yielded significance for the median RT (n = 13; $F(1,83) = 9.77$; $p = .002$), 10% fastest RT ($F(1,83.1) = 7.32$; $p = .008$), 10% slowest RT ($F(1,83) = 6.27$; $p = .014$), and the number of lapses ($F(1,82.1) = 6.51$; $p = .013$). Similarly, the main effect of sampling time was significant for the median RT ($F(3,83) = 4.23$; $p = .008$), 10% fastest responses ($F(3,83.1) = 2.62$; $p = .056$), 10% slowest responses ($F(3,83) = 6.45$; $p < .001$), and the number of lapses ($F(3,82.1) = 6.84$; $p < .001$), whereas the interaction glasses × sampling time was not significant. Figure 4 depicts the time course and main effect of optimal task performance (10% fastest RTs) for each condition.

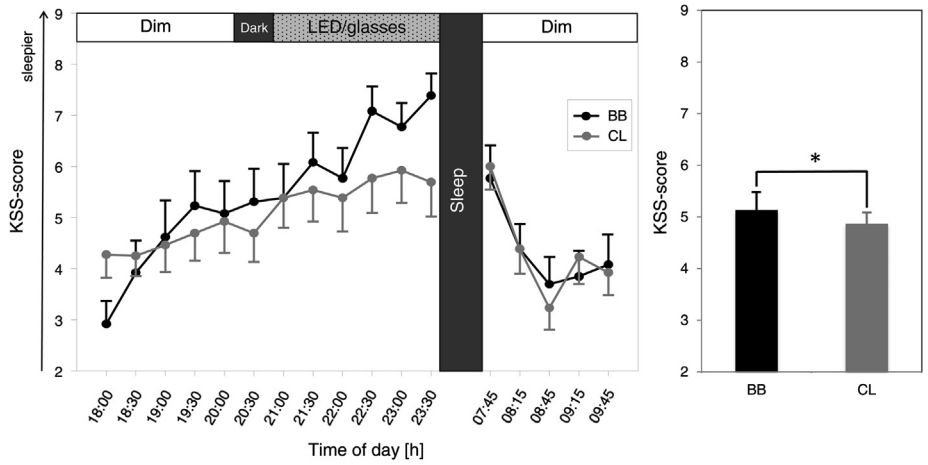

Figure 2. Subjective sleepiness (Karolinska Sleepiness Scale [KSS]) ratings of 13 male subjects (mean ± SEM) assessed on the KSS (1 = lowest score; 9 = highest score). Interaction between "glasses × sampling time" reached a statistical trend ($p = .063$; left panel for time course; the x-axis indicates the mean sampling time of day), although there was a significant main effect of the factor "glasses" (*$p = .027$; right panel). SEM = standard error of mean.

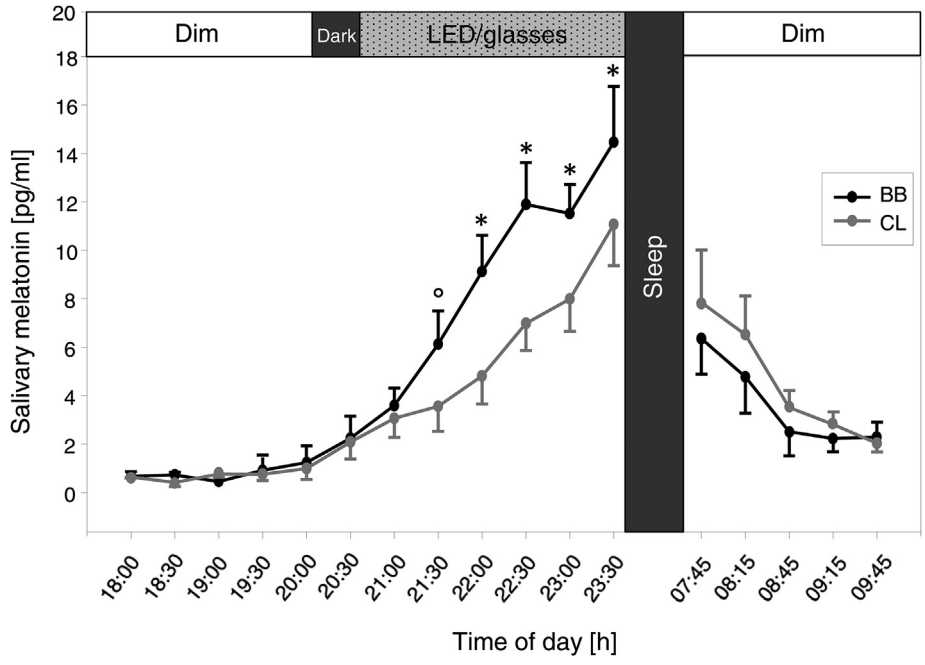

Figure 3. Melatonin profile of 12 male subjects (mean ± SEM). *indicates significant difference between BB and CL. A tendency is indicated by a circle (°). The x-axis indicates the mean sampling time of day. SEM = standard error of mean.

Sleep

Sleep data are summarized in Table 1. The factor glasses on visually scored sleep variables across the entire night did not yield significance for any specific EEG sleep parameter. Likewise, subjectively assessed sleep quality the next morning on the Leeds Sleep Evaluation Questionnaire did not differ significantly between the two conditions.

Discussion

Our data show that BB glasses can decrease LED screen–induced melatonin suppression and modulate subjective sleepiness and vigilance attention levels in the late evening hours in a sample of male adolescents. Compared with the control condition (CL glasses), our participants felt significantly more sleepy and less vigilant during the BB condition, although subsequent all-night sleep stage characteristics were not significantly altered. BB application can thus attenuate light-induced activating effects at the subjective and cognitive levels. These characteristics appear crucial with respect to the frequent and maybe inappropriate use of light-emitting and alerting multimedia screens before sleep onset during adolescence.

The circadian clock of adolescents has a markedly later circadian phase compared with older adults [3]. Eveningness is associated with a lack of morning light exposure [32] and disproportional evening exposure to artificial light sources. Especially blue-enriched light exposure in the evening hours

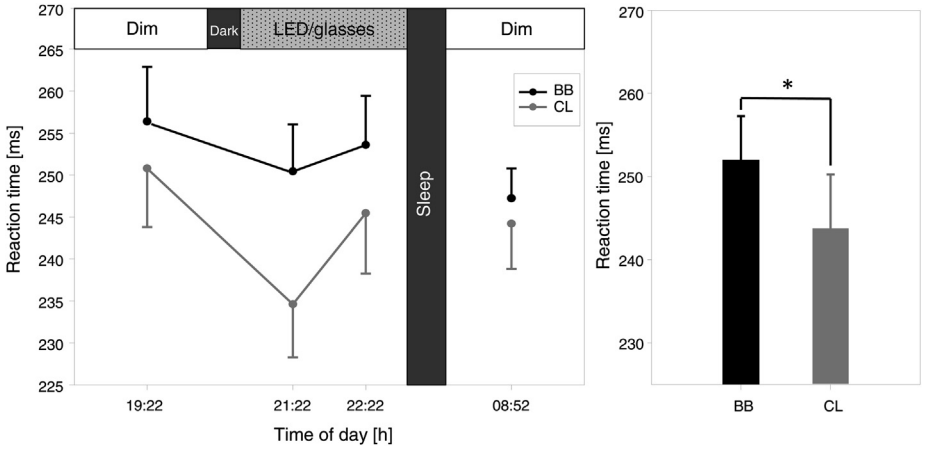

Figure 4. Psychomotor vigilance performance of 13 male subjects illustrated by 10% fastest reaction times. Left panel: time course, the x-axis indicates the mean sampling time of day. Interaction between "glasses × session" was not significant ($p = .452$, left panel). Right panel: main effect of the factor "glasses" (*$p = .008$).

Table 1
Visually scored sleep stages subsequent to the wearing of the BB and the CL glasses (n = 11)

Variable	BB	CL	*p* value
Bedtime (hh:mm)	23:47 ± 0:34	23:53 ± 0:31	.492
Get up time (hh:mm)	7:47 ± 0:34	7:53 ± 0:31	.492
Sleep quality	35.55 ± 12.53	33.05 ± 12.29	.722
TST (minutes)	428.27 ± 84.76	439.88± 46.53	.716
SL1 (minutes)	6.79 ± 5.86	4.85 ± 3.95	.179
SL2 (minutes)	13.45 ± 10.22	12.06 ± 9.04	.669
RL (minutes)	96.15 ± 45.77	100.82 ± 13.80	.731
MT (% of TST)	2.37 ± 1.29	2.35 ± .87	.953
Wake (% of TST)	4.20 ± 3.75	2.72 ± 1.51	.221
WALO (% of TST)	6.57 ± 4.41	5.07 ± 1.64	.199
Stage 1 (% of TST)	15.24 ± 6.01	15.22 ± 5.84	.993
Stage 2 (% of TST)	46.49 ± 5.05	46.54 ± 4.83	.983
Stage 3 (% of TST)	11.66 ± 2.98	10.64 ± 2.87	.383
Stage 4 (% of TST)	8.69 ± 4.39	10.64 ± 7.49	.269
SWS (% of TST)	20.36 ± 5.15	21.28 ± 7.49	.523
NREM (% of TST)	66.85 ± 4.93	67.83 ± 7.12	.678
REM (% of TST)	17.83 ± 3.52	16.88 ± 2.95	.515

Stage 1–Stage 4 represents sleep Stages 1–4 (in percentage of TST); wake represents wakefulness after lights off (percentage of TST).
Values are depicted as mean ± standard deviation.
Effect sizes are low to medium (Cohen's d = .003–.518).
BB = blue light–blocking glasses; CL = clear lenses; MT = movement time (% of TST); NREM = non–rapid eye movement sleep (Stages 2–4) (% of TST); REM = rapid eye movement sleep (% of TST); RL = REM sleep latency (after sleep onset); SL1 = sleep latency to Stage 1; SL2 = sleep latency to Stage 2; SWS = slow wave sleep (Stage 3 + Stage 4) (% of TST); TST = total sleep time; WALO = wake + movement time.

leads to increased alertness and cognitive performance [15]. Such arousing effects may be beneficial in the short run for learning or efficient work during the late evening hours, but theoretically, the price to pay may be a further phase delay in sleep timing, resulting in reduced sleep duration and consequently an accumulation of sleep debt, especially during school days when wake-up time cannot be delayed [33]. Contrary to these expectations, our results did not indicate different actimetric-derived sleep–wake timings according to BB or CL conditions, nor did we observe a shifted circadian phase, as measured by salivary melatonin concentration. Note here that our DLMO assessment might have been masked per se by the application of BBs and be only revealed by assessment 24 hours later. Additionally, 1 week of BB may not have been long enough to alter circadian phase effects of evening LED exposure.

However, blue-enriched LED screen light clearly had an immediate effect on the nocturnal rise of melatonin secretion when using CL glasses, and this could be prevented by BBs. This result supports previous findings showing that BBs attenuate melatonin suppression induced by a nocturnal light pulse in adults [21]. It further confirms that even the relatively low-level light exposure of LED screens is sufficient to suppress the evening melatonin rise [11] and that BBs prevent this light-induced suppressing effect [20] also in adolescents. Within this perspective, it might also be assumed that BBs affect the strength of light as a zeitgeber on circadian physiology by primary acting on its amplitude rather than on its phase. An enhanced circadian amplitude due to clear light–dark signals favors a good internal synchronization of multiple circadian processes in the body as well as a consolidated sleep–wake cycle and may positively affect health and well-being. Concomitantly, we observed a condition-dependent amplitude modulation of subjective sleepiness levels. Thus, subjects felt less sleepy in the early evening hours under BB conditions, but sleepiness increased more rapidly in the late evening hours approaching habitual bedtimes. Also, reaction times in a psychomotor vigilance task were slower during BB condition. Studies have observed that very short light pulses after 5 hours of wakefulness, especially within the short-wavelength spectrum, can modulate blood oxygen level–dependent activity of brain structures involved in alertness, thereby dynamically promoting cortical activity in networks involved in ongoing cognitive processes [34]. Thus, the use of blue light–enriched LED screens in the late evening hours may initiate activating mechanisms at a time of day more adapted to initiate sleep. Note that our study suggests that the glasses only modified vigilant attention and subjective sleepiness in the evening before sleep but not the morning after. Likewise, we did not observe differences in subsequent all-night electrophysiologically and actigraphically derived sleep parameters, although sleep has shown to be affected by previous light exposure (increased sleep latency, reduced slow-wave sleep and its associated EEG spectral power at the beginning of the night, and modified rapid eye movement sleep onsets) [15]. The use of BB in the evenings for at least 2 weeks improved subjectively assessed sleep quality [22], but 1 hour of bright compared with short-wavelength–filtered tablet screen-light exposure did not affect adolescents' sleep [35]. Maybe 1 week is too short to change sleep architecture. Furthermore, the study was performed during school time, during which the teenager's sleep–wake timing is strongly determined by the school schedule. In addition, the average sleep duration of approximately 6.5 hours led to accumulation of a sleep debt that is typical for this age group population and was confirmed in our cohort as indicated by a longer sleep duration at the weekends. The latter might have overruled potential effects of LED screen exposure and the application of BB glasses on electrophysiologically derived sleep parameters.

Note that this study presents some limitations. First, the BB and CL conditions not only differed with respect to transmission of blue light but also with respect to light intensity, both affecting circadian arousal regulation or more specifically, melatonin suppression and alerting responses at the behavioral level. However, as the main aim of the present study consisted in the exploration of BBs on subjective, cognitive, and physiological measures under teenager's real-life situations, we considered CLs as the most appropriate comparison. In a next step, it would be interesting to further investigate whether BBs modify adolescents' behavior and physiology before sleep by comparing it with a condition identical with respect to light intensity [21]. Future studies should also test stronger LED-light exposure (e.g., higher intensity, longer exposure duration, different exposure timing as for instance after habitual sleep onset; all affecting the acute nonvisual effects of light on human behavior). Moreover, given that a sample size of 13 healthy young males was used for this study, lack of significance for some measures could be because of lack of statistical power. Furthermore, the findings of this study may not be generalized to female adolescents. We included only males to eliminate a probable influence of the menstrual cycle, but studying the effect of BB glasses on females is an obvious next step. Finally, it would be interesting to investigate a population of adolescents suffering from circadian rhythm sleep disorders such as delayed sleep-phase syndrome because they might be particularly sensitive to the here-observed effects on circadian physiology.

We conclude that the use of BB glasses in male adolescents while sitting in front of an LED screen in the evening can attenuate melatonin suppression and alerting effects before sleep. BB glasses therefore have the potential to acutely impede the negative effects modern lighting imposes on circadian physiology in the evening. The impact on the circadian system implicates that multimedia screen use may be harmful for adolescents' health also in the long run and that BB glasses could serve as a countermeasure with beneficial effects on sleep quality, daytime functioning, and even mood.

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Supplementary Data

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