Revisiting the alerting effect of light; a systematic review

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Summary

Light plays an essential role in maintaining alertness levels. Like other non-image-forming responses, the alerting effect of light is influenced by its spectral wavelength, duration and intensity. Alertness levels are also dependent on circadian rhythm (Process C) and homeostatic sleep pressure (Process S), consistent with the classic two-process model of sleep regulation. Over the last decade, there has been increasing recognition of an additional process (referred to as the third process) in sleep regulation. This third process seems to receive sensory inputs from body systems such as digestion, and is usually synchronised with Process C and Process S. Previous studies on the alerting effect of light have been mostly conducted in laboratories. Although these studies are helpful in delineating the impact of Process C and Process S, their ability to assist in understanding the third process is limited. This systematic review investigated the factors that influence the alerting effect of light by examining randomized controlled trials and randomized or counterbalanced crossover studies. Factors that influence light’s alerting effect were examined with reference to the three-process model. The post-illuminance alerting effect was examined separately due to its potential to offer flexible workplace-based light interventions to increase or maintain employees’ alertness.

Keywords

Short wavelength light; intensity; sleepiness; alertness; circadian system, post-illuminance; three-process model

Abbreviation list

EEG Electroencephalogram
ipRGC Intrinsically photosensitive retinal ganglion cells
KSS Karolinska sleepiness scale
KGS Kwansei Gakuin sleepiness scale
MSLT Multiple sleep latency test
MWT Maintenance of wakefulness test
Introduction

As one of the most powerful environmental stimuli, light’s impact on humans extends beyond its classic visual function to other brain functions. These other brain functions are referred to as non-image-forming (NIF) responses to separate them from the classic visual responses to light. Examples of NIF responses include circadian rhythm phase shifting [1, 2], pupillary reflexes [3], mood changes [4], acute melatonin suppression [5, 6], improved cognitive function [7, 8] and the promotion of alertness levels [7, 9, 10]. Over the last decade [7, 11, 12], there has been growing interest in understanding the neurophysiological pathways via which light influences alertness levels, partly due to its potential to be applied in real world settings as a countermeasure for sleepiness.

Central to the physiology of light’s NIF responses, including light’s alerting effect, are the intrinsically photosensitive retinal ganglion cells (ipRGC) located in the retina. Although these ipRGCs only account for 1-5% of the total ganglion cells [13], their role in light’s NIF responses is fundamental and is independent of the classic visual system. For example, in completely blind participants, light is able to modulate electroencephalogram (EEG) activity and impact the subcortical areas that regulate alertness levels when participants are engaged in cognitive tasks [14]. ipRGCs primarily receive input from melanopsin, an ipRGC expressed photoreceptor [15], but also receive input from rod-cone networks [13]. Rods and cones are most sensitive to medium and long wavelength light, whereas
melanopsin photoreceptors have a maximum sensitivity to short wavelength light of 480nm (blue light) [13]. Predictably, blue light has been found to have a greater influence on the thalamus and the frontal and parietal cortical areas than green and violet light [8, 16]. In addition to wavelength, the alerting effect of light is also associated with the duration and intensity of light exposure. For instance, a dose-response relationship between light intensity and its alerting effect has been observed during biological night (11pm-7am for normal chronotypes) [17]. Furthermore, a longer duration of white intense light is predictive of larger brain activation [18]. Collectively, previous studies have clearly demonstrated the importance of light’s physical properties in promoting alertness levels; however, light’s alerting effect must also be considered within a broad sleep regulation framework.

The earliest and most tested model of sleep regulation is the two-process model, which comprises two separate processes [19]. Process C, representing the circadian rhythm, is usually high during the day to facilitate activity and low during biological night to facilitate sleep. Process S, representing sleep debt, increases during wakefulness and decreases during sleep. In this original model, these two processes interact only at discrete time points. The authors of the two-process model acknowledge that this model does not incorporate some of the complexities that have been discovered since its conception [19]. One complexity is the continuous and non-linear interaction between Process C and Process S, which allows immediate reciprocal feedback between these two processes. The other complexity is the non-Suprachiasmatic nucleus (SCN) oscillator that is linked to metabolic rate, which is further influenced by factors such as food intake and energy consumption. This non-SCN oscillator is usually synchronised with the central SCN clock, but can be desynchronised under certain conditions [19]. This continuous interaction between Process C and Process S was also recognised by another group of researchers led by Hubbard [11], who postulated a three-process conceptual framework of sleep regulation— that is, Process C, Process S and a direct effect— following their review of studies on transgenic mice. The direct effect in Hubbard et al.’s model refers to the direct effect of light on sleep that is independent of, but interacts with, circadian rhythm. The
idea of an additional process to Process C and S in regulating sleep was also proposed by Johns [20], who developed a similar conceptual framework. In Johns’ framework, this additional process is expressed as Process A, which works with Process C and Process S in regulating sleepiness. Process A represents an afferent process, integrating sensory inputs from body systems e.g. postural muscles [20]. Although different terms have been used by these researchers, all three groups suggest a new and independent process to Process C and Process S in regulating sleep. This new process seems to encompass a range of endogenous (e.g. chronotype) and exogenous (e.g. physical activity, food intake) factors that are often eliminated or controlled in laboratory studies for the purpose of disentangling the role of Process C and Process S in sleep regulation. However, to enable the application of light intervention as a sleepiness countermeasure in the real world, understanding how this third process impacts light’s alerting effect is vital.

The purpose of this review is to describe light intervention studies in reference to the three-process conceptual framework and considering the physical properties of light. While previous reviews aimed to clarify the underlying neurophysiological pathways via which light affects alertness levels, this current review aims to broadly document factors that influence the alerting effect of light in their most complete form, and search for patterns amongst both effective and non-effective light interventions. The results of this review will be briefly discussed in relation to the underlying physiological mechanisms as well as the methodological quality of the studies. The findings are particularly relevant to industries where alertness levels are crucial to the safety of clients, such as health care professionals and rail workers [21, 22], where poor decision-making has major consequences (e.g. death).

**Methods**

**Eligibility criteria**

**Study design**
Eligible studies were restricted to randomized controlled trials (RCT) and randomized or counterbalanced crossover studies. A counterbalanced crossover design was considered appropriate for testing the alerting effect of light, because the alerting effect of light is short-lived [23] and in people without significant sleep disorders, levels of alertness are generally stable. This criterion requires studies to explicitly state that participants were randomly allocated to different treatment conditions, or to order of treatment, or to state that the order of treatment was counterbalanced. To this end, studies using methods of non-random allocation to treatment (e.g. by participants’ office floor [24]) were excluded. Studies that failed to report the method for allocation to treatment were excluded without contacting authors for further details.

**Study participants**

Adults without medical conditions known to influence their alertness levels were included. Healthy employees or volunteers were both considered eligible. On the other hand, studies examining 1) people aged 55 years and above, or 2) a clinical population, such as patients with a diagnosis of Parkinson’s disease, depression, brain injury or dementia were excluded. Older people were excluded because there is evidence that the regulation of circadian rhythm weakens as people age [25], which might result in an attenuated alerting response to light intervention.

**Types of interventions**

Studies using light alone or with other interventions were selected. To enable the elucidation of the impact of intensity and spectral wavelength on the alerting effect of light, studies were required to report both aspects across treatment conditions to allow the differences in spectral distribution and illuminance level between intervention and controls to be determined. Light source (e.g. fluorescent, incandescent, daylight) was used as a proxy of spectral power distribution when the spectral power distribution or correlated colour temperature was not available. On the other hand, studies that failed to report intensity and/or spectral distribution for any treatment conditions were excluded.
For studies that used light and other forms of intervention (e.g. fixed sleep schedule), these studies were only included when light’s alerting effect could be ascertained.

**Outcome measures**

The outcome of interest for this review was alertness/sleepiness. Both subjective and objective alertness measurements were considered. Validated instruments for the measurement of subjective alertness included the Karolinska sleepiness scale (KSS)[26], Stanford sleepiness scale (SSS) [27], visual analogue scales (VAS) and other self-reported scales such as the Kwansei Gakuin sleepiness scale (KGS) [28].

Objective measures of alertness/sleepiness comprised EEG correlates which included alpha (8-12Hz), theta (4-8Hz) and delta power density (1-4Hz). Increased homeostatic sleep pressure has been found to result in increased frontal low EEG (theta/delta; 1-7Hz) activity [29]. Moreover, subjectively measured sleepiness has been found to be negatively associated with global alpha power density and positively associated with frontal theta power density (4-8Hz) [30]. Incidences of slow eye movements (SEMs) that occur before sleep onset are highly correlated with subjective sleepiness and EEG low frequency activity, although this relationship is almost exclusive to an eye closed condition [31] among sleep deprived participants. Also, the maintenance of wakefulness test (MWT) [32] and multiple sleep latency test (MSLT) were considered in this review. Behavioural alertness/sleepiness measures, such as cognitive performance tests were excluded as they vary in task difficulty, which is a factor that influences alertness [33].

**Electronic databases**

PubMed, EMBASE, PsycINFO and Scopus databases were searched until December 2016. A list of keywords and keyword combinations used is provided in Appendix 1.

**Study selection**
Study selection was completed using a three-step process. At Step 1, the titles and abstracts of returned citations were read by both authors. Studies that were clearly irrelevant to the topic or did not meet inclusion criteria were excluded. At Step 2, inspection of the full texts of the remaining studies was conducted by the two authors regarding their eligibility. At Step 3, key information from the remaining articles was extracted independently by the two authors, resulting in some studies being further excluded.

**Data extraction**

Data on study design, sample, light treatment profile and alerting effect were extracted. Study sample was described in terms of 1) occupation 2) sample size, 3) average age, 4) percentage of females, and 5) eligibility criteria to participate. Light treatment profiles included the 1) intensity and spectral wavelength of the light, 2) timing of light intervention, 3) duration of a single light intervention session, 4) the number of light treatment sessions within one 24-hour cycle, and 5) the number of 24-hour cycles. Participants’ sleep history in the 48 hours prior to light intervention was examined by documenting the sleep wake schedule and length of sustained wakefulness for the two nights prior to the light intervention. Prior light exposure immediately before intervention was also assessed. Lastly, the effectiveness of light treatment in improving alertness levels during and after light exposure was documented, respectively. A meta-analysis of the effect size of the alerting effect was planned; however, it was not possible because of the limited usable data and the heterogeneity of the studies.

**Risk of bias assessment**

Risk of bias assessment was undertaken using the guidelines for intervention studies from the Cochrane’s handbook [23]. For RCTs, the risk of selection bias, performance bias, detection bias, bias due to incomplete data and reporting bias were evaluated. For studies with a crossover design, the examination of possible carryover effects, the availability of a complete data set and the use of
paired analysis was examined. Risk of bias was evaluated by two authors. Disagreements were resolved through discussion.

**Results**

A flowchart of the literature screening process is presented in Figure 1. In total, 28 studies were included, with 24 studies examining the alerting effect of light during illuminance (see Table 1) and 14 investigating the post-illuminance effect (see Table 2). Of the 28 studies, 10 studies examined alertness levels both during and post-illuminance. Note, in presenting the results, the alertness level measured immediately after the completion of light intervention was classified as being during illuminance.

**Light interventions for promoting alertness DURING illuminance (N =24)**

Among the 24 studies that examined the alerting effect of light during illuminance, 11 studies were undertaken in the daytime, and 13 were conducted at night (see Table 1). Regarding study design, six of the 24 studies used a RCT design [9, 10, 33-36], and the remaining studies used a crossover design. Participants were all healthy volunteers, usually aged between 20 to 25 years, who underwent extensive screening before being recruited to the study. The sample sizes ranged from 8 [28, 37, 38] to 64 [39], and was generally around 10 to 20 participants.

a. **Daytime studies (N =11)**

Of the 11 daytime light studies, three studies [10, 39, 40] found a significant *during illuminance* alerting effect, six studies reported a non-significant alerting effect [33, 35, 37, 41-43] and two studies reported mixed results regarding the alerting effect of light where light had an alerting effect on an objective but not a subjective measure [34, 44]. The details of these studies are outlined below.

i. **Studies with significant alerting effect (N=3)**
The three studies [10, 39, 40] that observed a significant alerting effect all used a 1000lux fluorescent light as the intervention. Comparison light conditions differed slightly. One study [10] compared the intervention with a 3lux incandescent light and the other two studies [39, 40] compared their intervention with a 200lux fluorescent light of the identical colour temperature to their intervention light. Two studies delivered intervention light in an intermittent pattern [39, 40], and one study administered the intervention light in a continuous manner [10], with a total duration of light exposure ranging from 4 to 6hrs. A sleep restriction protocol was implemented in the study by Phipps-Nelson et al. [10], but not in the other two studies [39, 40]. In the study by Phipps-Nelson et al., participants were allowed to sleep 5hrs per night for the 2 nights prior. In terms of the prior light exposure, Smolders et al. [40] had participants undergo a 30-min adaption session under 200lux light (same as their control light condition), Phipps-Nelson et al. [10] had their participants exposed to dim light (<5lux) for about 6hrs, and Huiberts et al. [39] implemented a 25min adaption period using 100lux light. Smolders et al. [40] and Huiberts et al. [39] measured subjective sleepiness by KSS (average score), and Phipps-Nelson et al. [10] measured subjective sleepiness by KSS (average score) and objective sleepiness using SEMs.

ii. Studies with non-significant alerting effect (N=6)

The six studies that found non-significant results can be grouped according to the type of intervention light used. Two studies – one conducted by Munch & Jaeggie [41] and the other by Weisgerber et al. [42] – used broadband light of increased illuminance as the intervention. Four studies, conducted by Sahin & Figueiro [43], Okamoto & Nakagawa [37], Segal et al. [35] and Alkozei et al. [33] respectively, used monochromatic blue light as the intervention. The characteristics of these studies are provided below with reference to the three studies that reported a significant alerting effect where applicable.

Munch & Jaeggie’s [41] study is comparable to the three studies that found a significant alerting effect regarding the timing of the light intervention and sleep history (see Table 1). Noticeable
The differences between Munch & Jaeggie’s study and the three studies with a significant finding include the absence of a controlled adaption period before the light intervention, and that participants in this study were allowed to talk, read, write and listen to music during the intervention (Table 1). The intervention light used by Weisgerber et al. [42] had a much higher illuminance than that used in the three studies with significant results (5600lux vs. 1000lux). However, participants also had longer wakefulness (22hrs vs. 4-5hrs) before being exposed to the intervention light resulting in higher sleep pressure, and were exposed to a shorter intervention light session (48mins vs. 5-6hrs) compared to the three studies reporting a significant alerting effect. Furthermore, during light exposure, participants in Weisgerber et al.’s study were allowed to read and talk to the research assistant. Both of the studies measured subjective sleepiness only, using the KSS.

The irradiance/illuminance level of monochromatic blue light used was 40lux in Sahin & Figueiro’s study [43], 10lux in Okamoto & Nakagawa’ study [37], 2.8-8.4 x 10^{13} \text{photons/cm}^2/\text{s} in Segal et al.’s study [35], and 214lux in Alkozei et al.’s study [33]. The comparison light in these studies was 40lux red light [43], 10lux green and red light [37], 2.8-8.4 x 10^{13} \text{photons/cm}^2/\text{s} green light [35], and 188lux amber light [33], respectively. All four studies administered the light intervention over a single session, with the duration of the session ranging from 28mins [37] to 3hrs [35]. A sleep restriction protocol was implemented in the study by Segal et al. [35], where participants were allowed 8hrs sleep within the 48-hour period prior to the intervention. Participants’ regular sleep and wake schedule was used in the other three studies [33, 37, 43]. The duration of the dark/dim light adaption period varied among these studies, which were 10mins [37], 30mins [33], 42mins [43], and 3hrs [35], respectively. Sahin & Figueiro [43] and Segal et al. [35] measured both subjective sleepiness using the KSS and objective sleepiness using EEG correlates. Okamoto & Nakagawa [37] and Alkozei et al. [33] measured subjective sleepiness using the KSS and SSS.

**iii. Studies with mixed results for alerting effect (N =2)**
Rahman et al. [34] and Sahin et al. [44] found a significant alerting effect of light for objective sleepiness measured by EEG correlates, but no difference for subjective alertness. Rahman et al. [34] compared a 6.5hr blue monochromatic light of $2.8 \times 10^{13}$ photons/cm$^2$/s with green monochromatic light of the same photon density from 4.75hrs after participants’ individual wake times. Participants restricted their total sleep time to 8hrs over the 2 nights before light intervention. Also, a 4.75hr dim light (<3lux) adaption was implemented. Results of this study indicated no difference in the KSS, but a significant reduction of theta-alpha power density (less sleepiness) in the blue light group. The study by Sahin et al. [44] included two experiments. One compared white light of 361lux and 2568K with ambient white light of <5lux and 3500K, and the other compared red light of 213lux with ambient white light of <5lux and 3500K. Both of the experiments followed same protocol in that the participants maintained their regular sleep and wake schedule and underwent a dim light adaption period before the light intervention. Participants were exposed to a single 2hr light exposure session at one of three times (0700-0900; 1100-1300; 1500-1700). Neither intervention light influenced subjective alertness, but a reduction in alpha and theta-alpha power waves in the afternoon sessions, indicating an increased level of alertness, was found.

To summarise, it seems that fluorescent light of an illuminance of 1000lux of more than 2hrs duration is effective in promoting alertness levels during the daytime. In contrast, monochromatic blue light of low irradiance does not appear to be as effective in increasing alertness level during the daytime.

b. Night time studies (N =13)

Out of the 13 night time studies, five found a significant alerting effect of the intervention light [5, 6, 9, 45, 46], four studies found no alerting effect of intervention light [36, 47-49], and the remaining four studies reported mixed results on the alerting effect depending on the measurement of alertness [28, 38, 50, 51].

i. Studies with significant alerting effect (N=5)
All five studies used blue light of low irradiance; two studies used the monochromatic form [9, 45], and the other three studies used the broadband form (blue light enriched with white light) [5, 6, 46]. In the two studies that used blue monochromatic light as the intervention, green monochromatic light of the same photon density (2.8 x 10^{13} photons/cm^2/s) was the control [9, 45]. In the study led by Lockley [9], the duration of light intervention was 6.5hrs for 1 session and for 1 night, and in the study by Cajochen et al. [45], the light duration was 2hrs for 1 session and for 1 night. Dim light adaption was about 5hrs in both studies. A notable difference is that Lockley et al. restricted participants’ sleep time to 8hrs over the 2 nights before the intervention [9], whereas Cajochen et al. asked their participants to follow their usual sleep and wake schedule [45]. Lockley et al. found a reduction in KSS scores, a decrease in delta-theta power densities, and an increase in the high range alpha waves. Cajochen et al. measured subjective sleepiness only, using the KSS; lower sleepiness was reported by the intervention group.

Of the three studies that used broadband blue light, the irradiance of the intervention light was about 40lux [5, 6, 46], and that of control light varied from 1lux [46] to 40lux [5]. The duration of light intervention was 2hrs for 1 night in Chellappa et al.’s study [5], 5hrs for 1 night in Cajochen et al.’s study [6], and 4hrs/night for 5 nights in Chang et al.’s study [46]. Participants in all three studies followed their usual sleep and wake cycle prior to the intervention light, and those in Chellappa et al. [5] and Cajochen et al.’s [6] studies went through a dim light adaption period. In all of the studies, the KSS was used to measure level of sleepiness, and a reduction in KSS score was found. In the study by Cajochen et al. [6], objective sleepiness was further measured by SEMs, and a reduced incidences of SEMs were also confirmed.

\textit{ii. Studies with non-significant alerting effect (N = 4)}

Four night time studies [36, 47-49] failed to observe a significant alerting effect of the intervention light. Rangtell et al. [47] compared reading on an electronic device (102lux, 7718K) with reading a physical book under ambient room light (67.3lux, 2674K). The light exposure session was 2hrs for 1
night. This study was comparable to the three night time studies [5, 6, 46] that found a significant result regarding alerting effect of light, except for the adaption period. The light condition for their adaption period was 500lux and of 6.5hr duration [47], instead of dim or dark adaption reported in the three significant studies [5, 6, 46].

In the other three studies with non-significant results, short to medium wavelength filtered white light was compared with full spectrum white light of different illuminance levels [36, 48, 49]. Van der Werken et al. [48] compared <530nm filtered white light (193lux) with full spectrum white light (256lux); Rahman et al. [49] compared <480nm filtered (439lux) and <460nm filtered white light (459lux) with full spectrum white light (513lux), and Sasseville at al. [36] compared <530nm filtered white light with full spectrum white light (approx. 1200lux). In these studies, the intervention light contained less short wavelength (e.g. blue) light as well as having a lower illuminance level compared to their respective control light conditions. The duration of the light exposure was 8hrs for 2 nights in the study by van der Werken et al. [48], 12hrs for 1 night in the study by Rahman et al. [49], and 30mins for 1 night in the study by Sasseville at al. [36]. Using subjective sleepiness as the outcome measure, none of these studies found a significant difference across conditions.

Description of intervention light for studies with mixed results on alerting effect (N=4)

The four studies with mixed results for the alerting effect of light varied in terms of the physical properties of the intervention light.

Van der Lely et al. [51] used a similar approach to the two studies discussed earlier [48, 49], in that the authors compared filtered white light exposure to full spectrum white light. In this study [51], the light intervention was achieved by asking participants to wear blue blocker glasses from 1800hrs until bed time for 1 week at home, then 1 night in the laboratory. Those in the control group were exposed to the full spectrum of white light by wearing normal glasses. The illuminance level was 106lux for the intervention, and 103lux for the control condition. Measurements of both subjective and objective sleepiness were only assessed on the laboratory night, thus the results might reflect an
accumulative alerting effect. The authors found a higher level of subjective sleepiness (KSS) in the intervention group, but no difference for any EEG correlates.

In the study by Phipps-Nelson et al. [38], low irradiance monochromatic light (1.12-1.15lux) for 6hrs for 1 night was compared with low irradiance white light (0.02-0.2lux). Participants underwent an 8hr dim light adaption, and followed their usual sleep and wake schedule the night before the intervention. Using this protocol, the authors found no difference in subjective sleepiness as measured by KSS, but a significant reduction in theta and delta wave activities as well as SEMs incidences, suggesting a reduced level of sleepiness.

Lastly, two studies compared white light of moderate illuminance (2500-3000lux) with red light of low illuminance (4-24lux) [21] and white light (120lux) [31], respectively. In the study by Yokoi et al. [28], the duration of the light intervention was 7.5hrs for 1 night. In the study by Lavoie et al. [50], the duration of the light intervention was 4hrs for 1 night. Participants in both of the studies went through several hours of dim light adaption and followed their regular sleep and wake schedule before their light intervention. Yokoi et al. [28] reported no difference in the mean subjective sleepiness measured by KGS, but an increase in alpha wave activity at rest, which is an indicator of reduced sleepiness. Lavoie et al. [50] also failed to find a difference in subjective sleepiness using a VAS, but they reported a reduction in beta wave activity.

Taken together, blue light of low irradiance appears to be an effective measure in promoting alertness levels at night time in both monochromatic and broadband form. In contrast, white light of moderate illuminance was only effective in modulating objectively measured alertness levels. It appears that effective light treatment profiles differ diurnally. More importantly, subjective sleepiness measure seems to be less sensitive than objective sleepiness.

**Alerting effect of light POST illuminance: day & night time studies (N=14)**

Among the 14 studies that examined the post-illuminance alerting effect of light, five studies were RCTs [10, 33, 35, 52, 53], and the other nine studies used a crossover design. Participants were
mostly young and healthy adults, aged between 20 to 30yrs, except in one study, where some participants were aged in their 40s [38]. Sample size varied between 8 [38] and 90 [54], with many samples comprising 10 to 20 participants.

Studies investigating the alerting effect of light post-illuminance can generally be classified into three groups based on the time point when measurement of alertness occurs. The first group measured post-illuminance alertness within 24hrs after the light intervention before a sleep episode; the second group measured alertness within 24hrs after experimental light exposure, but after a sleep episode; and the third group measured alertness beyond 24hrs post-light intervention.

a. Post illuminance alertness within 24hrs before a sleep episode (N=10)

Of the 10 studies in this group, six were undertaken during the daytime [10, 33, 35, 41, 42, 55], and four were carried out at night [38, 45, 50, 54]. The six daytime studies are detailed first, followed by the four night time studies.

i. Daytime studies (N=6)

Of the six daytime studies, post-illuminance alertness was measured 2mins [55], 44mins [42], 2hrs [33, 41], 3hrs [35] and 4hrs [10] after the completion of the light intervention. The three studies that measured alertness at 2 to 3hrs post-illuminance observed no alerting effect of light [33, 35, 41], yet it should be noted that these studies observed no during illuminance alerting effect in the first instance. In the study by Phipps-Nelson et al. [10], the significant during illuminance alerting effect disappeared at the 4-hr post-intervention timepoint. In the study by Weisgerber et al. [42], no during illuminance alerting effect was found, but a significant alerting effect was recorded at 44mins after the completion of light intervention. Finally, a significant reduction of sleepiness was demonstrated 2mins after the light exposure by Leichtfried et al. [55].

The two studies reporting a significant post-illuminance alerting effect used moderate to high illuminance (1000lux and 5000lux) polychromatic light as the intervention [42, 55], and low...
illuminance white light as the comparison (400lux and <50lux). Leichtfried et al. [55] exposed participants to 5000lux fluorescent light from 0740 to 0810 for 1 day, and Weisgerber et al. [42] exposed participants to 48mins of 5600lux for 1 day after 22hrs of wakefulness. Participants in Weisgerber et al.’s study were allowed to talk and watch a movie during the light intervention, but then these activities were discouraged during the 44min driving test [42].

The characteristics of the four studies with a non-significant post-illuminance alerting effect of light have been discussed earlier. To reiterate briefly, two studies used monochromatic blue light as the intervention [33, 35], one study used daylight as the intervention [41], and the other study used high illuminance white light as the intervention [10]. The light exposure duration was 30mins for 1 day in the study by Alkozei et al. [33], 3hrs for 1 day in the study by Segal et al. [35], 6hrs for 1 day in the study by Munch & Jaeggie [41], and 5hrs for 1 day in the study by Phipps-Nelson et al. [10]. The post-illuminance alerting effect was measured under <2lux light in Segal et al.’s study [35], < 6lux light in Munch & Jaeggie’s study [41], <5lux light in Phipps-Nelson et al.’s study [10] and not reported by Alkozei et al. [33].

ii. Night time studies (N=4)

Of the four night time studies, the post-illuminance alertness level was measured at 45mins [54], 90mins [45], 1hr [50] and 2.5hrs [38] after the completion of light exposure. A significant post-illuminance alerting effect was reported by Karchani et al. [54] and Phipps-Nelson et al. [38]. The remaining two studies reported no post-illuminance alerting effect.

In the study by Karchani et al. [54], participants were exposed to 2500-3000lux fluorescent light during 15min work breaks with 4 breaks per night over 2 night shifts. The post-illuminance alerting effect was measured by the KSS 45mins after the light intervention under normal room light. No alerting effect during illuminance was obtained. Phipps-Nelson et al. [38] measured the during illuminance alerting effect of light both subjectively and objectively. They used blue light of a very low irradiance level as the intervention. Compared with white light of lower irradiance, a reduction in
SEM incidences and theta waves was recorded during illuminance, and sustained over the 2.5hrs post-illuminance in a similar light condition to their control.

Unlike the study by Phipps-Nelson et al. [38], the positive alerting effect found during illuminance in the studies by Cajochen et al.[45] and Lavoie et al. [50] both disappeared after the completion of light exposure. Cajochen et al. compared monochromatic blue light with green light (2.8 x 10^{13} photons/cm^2/s), and Lavoie et al. compared white light of increased illuminance (2300-4700lux) with red light of low illuminance (4-24lux).

b. **Post-illuminance alertness within 24hrs, but after a sleep episode (N=2)**

Two studies investigated the alerting effect of light after one night’s sleep. Both studies compared reading from an electronic device with reading a physical book [46, 47]. Results are mixed in terms of the alerting effect post-illuminance. In the study by Chang et al. [46], participants who read using an electronic device had less polysomnography (PSG) measured SEMs, prolonged sleep latency and reduced theta/alpha waves before sleep onset, and a higher level of sleepiness upon wakening.

Likewise, Rangtell et al. [47] assessed PSG measured sleep latency and EEG correlates after sleep onset, and subjective sleepiness via the KSS upon wakening, but the authors did not find a statistically significant difference in any of these aspects. Rangtell et al.’s [47] study differed from Chang et al.’s study in several ways; using a shorter duration of light exposure (2hrs vs 4hrs), less nights of light exposure (1 night vs. 4 nights), and a higher illuminance light condition for the adaption period (500lux vs. not reported).

c. **Post-illuminance alertness beyond 24hrs (N=2)**

Mixed results were found regarding the alerting effect of light beyond 24hrs. In the study by Horowizt et al. [53], participants were exposed to 2500lux fluorescent light for 6hrs over 3 nights, and a significant reduction in subjective sleepiness measured by a VAS on day 1 and day 2 after illuminance was revealed. Thessings et al. [52] reported two experiments with an identical protocol
except for the duration of the light exposure. Participants in one experiment were exposed to a very high illuminance light (8000-9000lux) for 2hrs for 1 night, and those in the other experiment were exposed to the same light intervention for 4hrs for 1 night. Post-illuminance alertness were measured by VAS and MSLT on the following night. The 2hr light exposure did not affect subjective or objective sleepiness. The 4hr light exposure shortened the sleep latency at one time point, but was not effective in reducing mean subjective sleepiness.

To summarise, the acute alerting effect of light does not seem to be sustained after the light intervention, but it is possible to alter one’s alertness level by phase shifting their circadian rhythm.

Discussion

The current systematic review identified a diurnal pattern in what constitutes an effective light intervention for reducing sleepiness. Blue light of low irradiance is clearly effective in reducing sleepiness during biological night, but its influence on alertness during the day is much less evident. In contrast, white light of moderate illuminance intensity is effective in reducing subjective sleepiness during the day. However, it is not effective in reducing subjective sleepiness at night, although an alerting effect was observed when an objective measure of alertness, such as EEG, was used. Most studies included in this review were conducted under controlled laboratory conditions, where environmental stimuli are minimised; thus limiting the generalisability of the findings to industry settings.

Modulation of circadian rhythm, sleep homeostatic pressure and light intensity

Among healthy, rested and room light adapted volunteers, a 1000lux white light was shown to be more effective in reducing subjective sleepiness than 150-200lux white light during the daytime [39, 40], except for the study by Munch et al. [41]. The two studies that reported a superior alerting effect had either the same correlated colour temperature between intervention and control groups (4000K) [39], or lower colour temperature in the intervention (4000K) than the control (6500K) [40].
In the study by Munch et al. [41], the intervention light source used was daylight and/or fluorescent light to generate an intensity of 1000lux depending on the time of the day. Therefore, it is reasonable to assume that the colour temperature of the intervention light would be cooler than that of the control light source (3700K). Had participants not been exposed to daylight on the commute to the laboratory, an alerting effect might have been observed in the intervention group. In contrast to daytime studies, a 2800lux white light made no difference to subjective sleepiness compared to a 120lux white light during biological night among similar participants [28]. In this study, although both control and intervention lights were generated by fluorescent light tubes, it was not stated whether the same type of fluorescent tube was used for both conditions. Regardless, the available evidence seems to suggest that the minimum light intensity required to stimulate a subjective feeling of alertness is much higher during the day due to low sleep pressure and a rising circadian drive. At night, sleep pressure has accumulated, which in combination with a decreasing circadian drive results in a lower alertness level, which means people may be more sensitive to light intervention. The differing threshold in light intensity seems to fit well with the two-process sleep model [56]. As indicated by the results of an earlier study on the dose-response relationship of white light on alertness at biological night, although a 230lux white light was superior to 23lux white light, a further increase to 3190lux did not result in a further reduction in either subjective or objective sleepiness [17]. In contrast to our results, Ruger et al. found that a 5000lux white light was effective in reducing subjective sleepiness both during the day and at night compared to a <10lux white light [57]. Yet, it should be noted that participants in their study went through a dim light adaption, and more importantly, a much lower intensity control light condition. Prior light exposure or darkness exposure, as discussed later in detail, does impact the effectiveness of light intervention on alertness. Although a dose-response relationship has been demonstrated during biological night, this relationship has not been examined during the daytime. Further, how this dose-response relationship varies according to wavelength is unknown.

Modulation of circadian rhythm, sleep homeostatic pressure and light wavelength
The present review clearly shows that low irradiance blue light was more powerful in reducing subjective sleepiness than monochromatic green light of the same photon density during biological night in both rested [45] and sleep deprived participants [9]. This observation is consistent with the findings of a rodent study carried out by Pilorz et al. [58], where high intensity blue light produced a greater arousing effect in mice as manifested by delayed sleep onset, behavioural aversion and high corticosterone levels in nocturnal mice compared to green light of the same photon density during night time. Different to the night time studies presented in this review, low irradiance blue light was not more alerting than green light of the same photon density when applied during the daytime [35, 37]. This diurnal difference in relation to the alerting effect of different spectrums can be explained by the three-process model of sleep regulation developed by Hubbard and colleagues [11, 59]. Light is alerting in humans, and according to this model, at night, blue light stimulates the melanopsin receptor that plays a dominant or sole role in activating the circadian rhythm, sleep pressure and direct effect processes, whereas green light only makes a small contribution to the alerting effect of light via the direct effect process and circadian rhythm mediated by rods and cones. During the daytime, green light takes a major role in increasing alertness level via rods and cones via the direct effect pathway. The alerting effect produced by green light may be equivalent to the alerting effect produced by blue light through melanopsin via the circadian rhythm. This might explain the non-significant differences seen between blue and green light during the day.

**Other influencing factors for alertness**

Most of the included studies examined healthy participants with non-extreme chronotypes, except for the study by van der Ley [51], where participants were adolescents with moderate to extreme eventing chronotypes. Chronotype has been identified as a personal trait that modulates the alerting effect of light. As summarised by Gaggioni et al. [60] in relation to cognitive function, during biological night, blue light is less beneficial for participants with an evening chronotype than participants with a morning chronotype, because participants with evening types have a stronger
compensation mechanism to oppose the adverse effect of a combination of a low circadian drive and high sleep pressure than participants with morning types. The inclusion of participants with a moderate to extreme evening chronotype in van der Ley’s [51] study might explain why no differences in EEG data were observed between the filtered blue light and full spectrum white light conditions. However, it is hard to explain why a significant reduction in subjective sleepiness was observed in the filtered blue light condition.

During the assessment of sleepiness, most of the included studies required that participants simultaneously completed monotonous activities. For three studies [28, 41, 42], participants were allowed to speak with each other or a research assistant. Talking to other people is known to promote greater alertness compared to sitting alone [61], because during an executive task, thalamus, a key brain structure linking alertness and cognition [8] is consistently recruited. This might explain the findings of Weisgerber et al. where no difference in alertness was found during the light intervention when participants were allowed talk; and yet a significant alerting effect was seen 45 minutes after the light exposure [42].

**Waking EEG correlates in relation to Process C and Process S**

Among studies where EEG correlates were used as an objective measurement for sleepiness, alpha, theta and delta bands were measured. In the studies included in this review, the definitions used for these wave bands were very similar to those proposed by Cajochen and colleagues [29], with alpha defined as 8-12Hz, theta as 4-8Hz, and delta as 1-4Hz. Some combined wave bands of alpha and theta were also used [34, 43, 44, 50], and in two studies, specific wave activity was not differentiated due to an overall non-significant finding [35, 51]. Both subjective and objective measures of sleepiness (e.g. EEG correlates) measure a state of drowsiness [20]. These measures demonstrate high agreement. When the presence of an alerting effect of light differs according to the measurement type, it is usually the case that the objective measurement, but not subjective measures, demonstrates an alerting effect [34, 38, 44]. This pattern seems to indicate that subjective
measures are less sensitive to changes in alertness compared to objective measures. In the current review, the only exception to this pattern is van der Ley’s [51] study where a difference in subjective alertness was observed when no effect on EEG was found.

Prior light exposure/sustained alerting effect of light

Some preliminary conclusions about the post-illuminance alerting effect of light can be drawn from this review. First, prior light exposure does seem to attenuate the alerting effect of the light intervention. For example, in the study by Rangtell et al. [47], 102lux light of a colour temperature of 7718K failed to elicit an alerting effect compared to a 67.3lux light of 2674K, whereas other similar studies [6, 46] observed a significant alerting effect. This is likely to be associated with the 6.5hr of 500lux prior light exposure. Prior daylight exposure is also likely to be explanation for the non-significant alerting effect of the intervention light observed in Munch & Jaeggie’s study [41]. A similar effect has also been demonstrated in rodent models, where the effect of the light/dark cycle extends for several hours [62]. Second, the time of day that the alerting effect was measured is likely to have moderated the post-illuminance alerting effect of light. In the daytime study by Phipps-Nelson et al. [10], the non-significant post-illuminance alerting effect was measured at 2100hrs when the circadian drive for alertness was at its highest (for participants without extreme chronotypes [56]), which might have masked the post-illuminance effect. In their night time study [38], the post-illuminance alerting effect was measured at 0930 in almost complete darkness, and the reduction of delta, theta waves and SEMs observed during blue light condition persisted. Together, these results lend support to the notion that an alerting effect of light can be sustained beyond the immediate light exposure (see also Hubbard et al. [11]). To date, many of the studies that examined the post-illuminance alerting effect of light have measured this effect under a dim light condition, where the alerting effect of light dissipates quickly. However, these conditions do not mimic those of industry and such dim lighting are rarely seen in some workplaces such as hospitals. Therefore, future research should also investigate the optimal light intervention for the purpose of producing an
adequate post-illuminance alerting effect of light under room light conditions. This question is meaningful for the health industry in particular, where staff and patients require different light/darkness exposure, especially at night. Tanaka et al. [63] reported that a 10min bright white light exposure was effective in reducing subjective sleepiness at 3hrs post-illuminance under room light conditions when completing normal work activities, but this study was not included in this review because the light properties of the intervention were not reported.

Risk of bias assessment results

Overall, the studies included in this review demonstrated high internal validity. As indicated in Figures 2 & 3, it is common for studies to not report information that allows for the assessment of the risk of bias associated with random sequence generation, allocation concealment and outcome assessment. However, we stress the difference between reporting and executing, and therefore, our assessment of bias may overestimate the risk of bias. With regard to the crossover trials, the proportion of studies reporting the results of an assessment of possible carryover effects was low. Furthermore, paired analysis was used in all but two studies [49, 55]. Yet, the use of unpaired analysis is likely to result in an underestimation of the true effect size. Therefore, it may be that light intervention is more effective than indicated here.

Conclusion

Blue light of low irradiance is probably an effective light intervention for increasing alertness levels at night, but is less effective during the daytime. Moderate bright light is likely to be effective in reducing sleepiness during the daytime, but might be less effective at night. Environmental factors (including prior light exposure) and individual factors (including chronotype and the activities undertaken during the measurement of sleepiness) influence the alerting effect of a light intervention. The development of light therapy as a sleepiness prevention strategy requires researchers not only to report the most complete form of the light’s physical properties [13], but also to report other detailed information in relation to the third process that may contribute to sleep
regulation in addition to Process C and Process S. Investigation of the dose-response relationship between specific light interventions and the alerting effect during the daytime and how this is influenced by spectral wavelength is also recommended. Knowledge gained from such research will eventually assist in the development and use of suitable light infrastructure and light interventions for various workplaces.

**Practice points**

1. The minimum light intensity required to induce an alerting effect is higher during the day than at night, and this minimum light intensity is likely to vary with the spectral distribution of light.
2. Light’s alerting effect is not only modulated by Process C and Process S, but also by the third process, which has been referred to as Process A, or the direct effect of light.
3. The alerting effect of light is likely to be sustained beyond the light intervention, but its impact will be highly dependent on other factors.

**Research agenda**

1. Investigate the dose-response relationship between various light properties and its alerting effect during the day to determine the minimum intensity required in relation to spectral wavelength distribution.
2. Investigate the post-illuminance alerting effect of light, considering the circadian rhythm (Process C), sleep homeostasis (Process S) and other environmental stimuli and personal traits (the third process).
3. Explore the use of brief light interventions at the beginning of a work shift as a method to increase alertness during the work period.
References


2. Dewan K, Benloucif S, Reid K, Wolfe LF, Zee PC. Light-induced changes of the circadian clock of humans: increasing duration is more effective than increasing light intensity. *Sleep* 2011; 34: 593-599.


37. Okamoto Y, Nakagawa S. Effects of daytime light exposure on cognitive brain activity as measured by the ERP P300. Physiol Behav 2015; 138: 313-318.


40. Smolders KCHJ, de Kort YAW, Cluitmans PJM. A higher illuminance induces alertness even during office hours: Findings on subjective measures, task performance and heart rate measures. Physiol Behav 2012; 107: 7-16.


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### Table 1: Studies examining the alerting effect of light DURING illuminance (n = 24).

<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design Setting</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
<th>Sleep history 24 hrs prior to intervention</th>
<th>Time of intervention delivery within one 24hr cycle</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Subjective sleepiness measurement</th>
<th>Objective sleepiness measurement</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phipps-Nelson et al. 2003 [10]</td>
<td>RCT, Random allocation reported, Lab – modified constant routine</td>
<td>Volunteers</td>
<td>Dim light of &lt;50lux from awakening to 1200hrs</td>
<td>Sleep restriction protocol applied: 5hrs/night for 2 nights before light intervention</td>
<td>DAYTIME (1200-1700) 5hrs/session 1 day</td>
<td>White light 1056lux</td>
<td>White light 3.3lux</td>
<td>KSS Yes, intervention light significantly reduced subjective sleepiness (a lower KSS score) compared to the control light.</td>
<td>SEM incidents Yes, intervention light significantly reduced objective sleepiness (reduced SEM incidences) than dim light</td>
<td>Wore EEG electrodes, and ate in a modified constant routine</td>
</tr>
<tr>
<td>Smolders et al. 2012 [40]</td>
<td>Crossover, WP unclear, Order of light treatment counterbalanced, Lab -simulated office room</td>
<td>Student volunteers</td>
<td>200lux (4000K) for 30 minutes prior to experiment</td>
<td>Nill sleep restriction</td>
<td>DAYTIME Morning session: 0900-1000 OR 1100-1200</td>
<td>White light 1000lux at eye level</td>
<td>White light 200lux at eye level</td>
<td>KSS N/A</td>
<td>In Block 1, 2 &amp; 3: EEG (eye open and closed) + auditory PVT + LDST + Questionnaire</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Daytime: High intensity white light.
- DML: Dim light of <5lux from awakening to 1200hrs.
- SEM: Sleep Efficiency Measure.
- PVT: Psychomotor Variable Test.
- NC: Non-REM Sleep + Questionnaire.
<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design</th>
<th>Setting</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
<th>Sleep history</th>
<th>Time of intervention delivery</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Subjective sleepiness measurement</th>
<th>Objective sleepiness measurement</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munch et al. 2012 [41]</td>
<td>Crossover</td>
<td>WP = 16 hours</td>
<td>Volunteers</td>
<td>Nil sleep restriction</td>
<td>24 hrs prior to intervention</td>
<td>DAYTIME (1200-1800)</td>
<td>White light 1000lux at eye level</td>
<td>White light 176lux at eye level</td>
<td>KSS N/A</td>
<td></td>
<td>\begin{itemize} \item Participants allowed to read, write, listen to music and talk (no laptops) \item Completed KSS, subjective wellbeing questionnaire every 30mins \end{itemize}</td>
</tr>
<tr>
<td></td>
<td>Randomisation of order reported</td>
<td>Lab</td>
<td>N = 29</td>
<td>Participants kept regular sleep and wake schedule</td>
<td>6hrs/session</td>
<td></td>
<td>Daylight ± fluorescent light of 1000lux to maintain above 1000lux</td>
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</tr>
<tr>
<td></td>
<td>Lab</td>
<td>Volunteers</td>
<td>Mean age: 23.6 yrs</td>
<td>Morning light exposure was not controlled</td>
<td>1 day</td>
<td></td>
<td>Participants were awake for 4-5hrs prior to light intervention</td>
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<tr>
<td></td>
<td></td>
<td>Non-smokers</td>
<td>Moderate consumption of caffeine and alcohol generally; refrain from caffeine and alcohol on the study day</td>
<td>Nil sleep restriction</td>
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<tr>
<td></td>
<td></td>
<td>Moderate consumption of caffeine and alcohol generally; refrain from caffeine and alcohol on the study day</td>
<td>No current regular medication</td>
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<tr>
<td></td>
<td></td>
<td>Moderate consumption of caffeine and alcohol generally; refrain from caffeine and alcohol on the study day</td>
<td>No medical or psychiatric disorders</td>
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<tr>
<td></td>
<td></td>
<td>Moderate consumption of caffeine and alcohol generally; refrain from caffeine and alcohol on the study day</td>
<td>No shift work or cross time zone travelling in past 2 mths</td>
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<tr>
<td></td>
<td></td>
<td>Moderate consumption of caffeine and alcohol generally; refrain from caffeine and alcohol on the study day</td>
<td>28 normal chronotype, 1 morning type</td>
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</tbody>
</table>

Munch et al. 2012 [41] report that daylight exposure on the commute from home to the lab is likely to be more effective in reducing sleepiness than office light (no difference).

Huiberts et al. 2015 [39] conducted a study with a crossover design, randomisation of lighting conditions, and volunteers aged 21.4 yrs with 50.0% female. The study included 64 participants who were divided into two groups based on lighting conditions. The study found that intervention light was effective in reducing sleepiness than RL in the morning, but not in the afternoon (no difference).

Huiberts et al. 2015 [39] also reported that daylight was not controlled in this study, and participants spent more time outside during the intervention period.
<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design</th>
<th>Setting</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
<th>Sleep history</th>
<th>Time of intervention delivery</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Subjective sleepiness measurement</th>
<th>Objective sleepiness measurement</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weisgerber et al. 2017 [42]</td>
<td>Crossover balanced design</td>
<td>WP ≥ 1wk, Lab – simulated driving session</td>
<td>Volunteers, N = 19, Mean age: 22.8 yrs, 31.6% female, No sleep disorder, No use of sleep medications, No use of NSAID, Healthy, No shift work and travelling across time zones in the past 3mths, No extreme chronotype</td>
<td>Sleep deprivation group: 35lux (incandescent) for 6hrs starting from participants’ usual bed time</td>
<td>24 hrs prior to intervention</td>
<td>1 day</td>
<td>CCT 4000K</td>
<td>CCT 4000K</td>
<td>White light</td>
<td>White light</td>
<td>KSS, measured 4 times during light exposure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sleep deprivation group: Sleep restriction protocol applied: no sleep was allowed the night before light treatment. Participants were awake for 22hrs before light treatment.</td>
<td>45mins/session</td>
<td>1 day</td>
<td>5600lux at eye level</td>
<td>Fluorescent</td>
<td>Incandescent</td>
<td>No, intervention light was not effective in reducing sleepiness than control light (KSS measured immediately after light exposure)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rested group: Various daylight (dawn light) for 45mins from usual wake up time to arrival at the lab</td>
<td>45mins/session</td>
<td>1 day</td>
<td>40lux</td>
<td>5000K Sunbox K10 model, sunbox, USA + 4100 K SADelite lamp Northern Lights Canada</td>
<td>No further information available</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rested group: DAYTIME (from awakening)</td>
<td>45mins/session</td>
<td>1 day</td>
<td>CCT 4100-5000K</td>
<td>KSS</td>
<td>N/A</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rested group: Nil sleep restriction. Participants were awake for 45mins before light treatment</td>
<td>45mins/session</td>
<td>1 day</td>
<td>3lux light for 30min preparation (1400-1430hrs)</td>
<td>Blue light = 460nm</td>
<td>Red light = 630nm</td>
<td>Alpha (8-12Hz)</td>
<td>EEG electrodes attached + KSS 4 times</td>
</tr>
<tr>
<td>Sahin &amp; Figueiro 2013 [43]</td>
<td>Crossover</td>
<td>WP = 1 wk, Presentation order counterbalanced</td>
<td>Volunteers, N = 13, Mean age: 20.5 yrs for males, and 21 yrs for females, 38.5% female</td>
<td>&lt; 2lux light for 30min preparation (1400-1430hrs)</td>
<td>Dark adaption</td>
<td>DAYTIME (1442-1530)</td>
<td>Blue light = 460nm</td>
<td>40lux</td>
<td>Alpha (8-12Hz)</td>
<td>Theta (4-8Hz)</td>
<td>alpha-theta (5-9Hz)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lab</td>
<td></td>
<td>DAYTIME = 5600lux at eye level</td>
<td>5000K Sunbox K10 model, sunbox, USA + 4100 K SADelite lamp Northern Lights Canada</td>
<td>40lux</td>
<td>5000K Sunbox K10 model, sunbox, USA + 4100 K SADelite lamp Northern Lights Canada</td>
<td>4100 K SADelite lamp Northern Lights Canada</td>
<td>40lux</td>
<td>No, blue light was not effective in</td>
<td>EEG at F, P, T, O 10-20system</td>
</tr>
<tr>
<td>Citation</td>
<td>Study design Setting</td>
<td>Sample</td>
<td>Light condition for the adaption period</td>
<td>Sleep history 24 hrs prior to intervention</td>
<td>Time of intervention delivery within one 24hr cycle</td>
<td>Intensity (lux) of intervention</td>
<td>Intensity (lux) of control</td>
<td>Subjective sleepiness measurement</td>
<td>Objective sleepiness measurement</td>
<td>Participants’ activities during sleepiness assessment</td>
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</tr>
<tr>
<td>Rahman et al. 2014 [34]</td>
<td>• RCT • Random allocation to light treatment reported • Lab</td>
<td>• Volunteers • N = 16 • Mean age: 24.8 yrs • 0% female • No use of caffeine, alcohol, smoking, over the counter and recreational drugs within 3wks before light exposure • No physical, psychological, and ophthalmic conditions • Maintained a self-selected 8hr sleep-wake schedule for 3wks before the light intervention • No report of chronotypes</td>
<td>• No alcohol or caffeine intake within 12hrs before experiment • No physical and mental health problems • No colour blindness • No shift work or cross time zone travelling in the past 3mths • No extreme chronotype for 12mins</td>
<td>the night before light treatment Participants were awake for about 7hrs before light treatment</td>
<td>DAYTIME (~4.75hr after individual’s wake time) 6.5hrs/session 1 day</td>
<td>40.2µW/cm²  µW/cm²</td>
<td>reducing subjective sleepiness than red light (no differences)</td>
<td>EEG when awake No, blue light was not effective in reducing objectively measured sleepiness than red light (no difference)</td>
<td>stare at the light source. No eating, drinking, and talking allowed.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Okamoto &amp; Nakagawa 2015 [37]</td>
<td>• Crossover • WP not reported • Order of light treatment counterbalanced • Lab</td>
<td>• Volunteers • N = 8 • Mean age: 22.9 yrs • 0% female • Non-smokers • No caffeine and alcohol within the 12hrs</td>
<td>&lt; 3lux fluorescent light for the 4.75hrs from awakening Sleep restriction applied: No sleep for the 1st night, and 8hrs/night for the 2nd night before light treatment Participants were awake for 4.75hrs prior to light intervention</td>
<td>DAYTIME (1200-1600) 28mins/session for 1 session</td>
<td>Monochromatic blue light of 460nm photon density 2.8x10¹³ photons/cm²/s Irradiance: 12.1µW/cm²</td>
<td>&lt; 15nm half peak bandwidth</td>
<td>N/A</td>
<td>N/A</td>
<td>Seated and gazed at the light source, completed auditory PVT and KSS tasks every 60mins</td>
<td></td>
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</tbody>
</table>

Note: DAYTIME refers to the daylight exposure period. KSS stands for Karolinska Sleepiness Scale.
<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design Setting</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
<th>Sleep history 24 hrs prior to intervention</th>
<th>Time of intervention delivery within one 24hr cycle</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Subjective sleepiness measurement</th>
<th>Objective sleepiness measurement</th>
<th>Outcome of light intervention</th>
<th>Outcome of light intervention</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segal et al. 2016 [35]</td>
<td>RCT</td>
<td>Volunteers</td>
<td>&lt;3 lux ambient fluorescent light for 3.25hrs from awakening.</td>
<td>Sleep restriction applied: 5hrs/night for night 1 and 3hrs/night for night 2 before light treatment.</td>
<td>1 day</td>
<td>Photo density: 33.9 x 10^{12} photons/cm^2/s</td>
<td>Photon density: 4.9 x 10^{12} photons/cm^2/s</td>
<td>reducing subjective sleepiness compared to medium and long wavelength light.</td>
<td>2 Monochromatic long wavelength light 620nm</td>
<td>10lux</td>
<td>2 Monochromatic long wavelength light 620nm</td>
<td>No, blue light is not effective in reducing subjective sleepiness than green light (no difference)</td>
</tr>
<tr>
<td></td>
<td>Random allocation reported</td>
<td>Lab</td>
<td>&lt;3 lux ambient fluorescent light for 3.25hrs from awakening.</td>
<td>Sleep restriction applied: 5hrs/night for night 1 and 3hrs/night for night 2 before light treatment.</td>
<td>1 day</td>
<td>Photon density: 2.8 x 10^{13} photons/cm^2/s at Melbourne</td>
<td>Photon density: 2.8 x 10^{13} photons/cm^2/s at Melbourne</td>
<td>KSS, measured 4 times</td>
<td>No, blue light is not effective in reducing subjective sleepiness than green light (no difference)</td>
<td>No, as there was no difference in any EEG bins between blue and green light</td>
<td>From awakening to 9.25hrs after awake, participants did PVT, KSS, KDT tests every 30 to 60mins</td>
<td>Participants performed the Stroop task and 2-</td>
</tr>
<tr>
<td>Citation</td>
<td>Study design</td>
<td>Setting</td>
<td>Sample</td>
<td>Light condition for the adaption period</td>
<td>Sleep history 24 hrs prior to intervention</td>
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<td>Intensity (lux) of intervention</td>
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<tr>
<td>Alkozei et al. 2016 [33]</td>
<td>RCT</td>
<td>Lab</td>
<td>Volunteers</td>
<td>• Alcohol consumption &lt; 14U/wk in the past 12mths</td>
<td>were awake for 3.25hrs prior to light treatment</td>
<td>Nil sleep restriction</td>
<td>Blue light = 469nm</td>
<td>Amber light = 578nm</td>
<td>SSS, measured at the end of light exposure</td>
<td>N/A</td>
<td>In a seated position, gaze at the light source, completed n-back task</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>N = 35</td>
<td>Amber light exposure for 30mins (0945-1015) in a darkened room</td>
<td></td>
<td>FOLLOWED USUAL SLEEP-WAKE SCHEDULE</td>
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<td></td>
<td></td>
<td></td>
<td>Mean age: 22yrs</td>
<td>DAYTIME (1015-1045)</td>
<td></td>
<td>DAYTIME (1001-1045) 30min/session</td>
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<td></td>
<td></td>
<td></td>
<td>50.8% female</td>
<td>1 day</td>
<td></td>
<td>1 day</td>
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<td></td>
<td></td>
<td>Right handed</td>
<td>Blue light = 214lux</td>
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<td>Blue light = 188lux</td>
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<td></td>
<td></td>
<td></td>
<td>primary English speaking</td>
<td>Panel irradiance: 1.23mW/cm²</td>
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<td>Panel irradiance: 0.35mW/cm²</td>
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<td></td>
<td></td>
<td></td>
<td>free from psychiatric, neurological, and substance use disorder</td>
<td>No, blue light is not effective in reducing subjective sleepiness than amber light</td>
<td></td>
<td>No, white light was not effective in reducing subjective sleepiness than white bright light</td>
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<td></td>
<td></td>
<td></td>
<td>Regular sleep and wake habits, which could have included extreme chronotypes</td>
<td>Pupils dilated</td>
<td></td>
<td>Pupils dilated</td>
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<td></td>
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<td></td>
<td>&lt; 5lux fluorescent light (3500K) from awakening (at 6hrs) until light treatment</td>
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<tr>
<td>Sahin et al. 2014 [44] experiment 1</td>
<td>Crossover</td>
<td>Lab</td>
<td>Volunteers</td>
<td>Nil sleep restriction</td>
<td>DAYTIME 0700-0900 OR 1100-1300 OR 1500-1700 2hrs/session</td>
<td>White light (380nm-730nm)</td>
<td>Ambient white light</td>
<td>KSS, measured 4 times</td>
<td>Alpha (8-12Hz), alpha-theta (5-9Hz)</td>
<td>Saliva sample+ KSS+EEG + GONOGO + MAT</td>
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<td></td>
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<td></td>
<td>N = 13</td>
<td>Regular sleep and wake schedule 2230-0600</td>
<td></td>
<td>Luxeon M3-</td>
<td>Fluorescent</td>
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<td></td>
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<td></td>
<td>Mean age: 23.0 yrs</td>
<td>DAYTIME</td>
<td></td>
<td>361lux</td>
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<td></td>
<td>43.8% female</td>
<td>0700-0900 OR 1100-1300 OR 1500-1700 2hrs/session</td>
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<td>1.1w/m²</td>
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<td>No smoking</td>
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<td>361lux</td>
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<td>No major health issues</td>
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<td>1.1w/m²</td>
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<td>Citation</td>
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<td>Time of intervention delivery within one 24hr cycle</td>
<td>Intensity (lux) of intervention</td>
<td>Intensity (lux) of control</td>
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<td>Objective sleepiness measurement</td>
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<tr>
<td>Sahin et al. 2014 [44] experiment 2</td>
<td>Crossover WP = 1 wk Order of light treatment counterbalanced Lab</td>
<td>Volunteers N = 13 Mean age: 23.0 yrs 43.8% female Non-smokers No major health issues No use of prescription medication No colour blindness No travel across more than two time zones during the last mth prior to the study Chronotype = 3.5 ±1.9, which could have included extreme types</td>
<td>Participants were awake for 1 hr before the 1st session</td>
<td>PW71 white light emitting LEDs CCT 2568K</td>
<td>Ambient white light (no difference)</td>
<td>Alpha-theta waves at session 2 and 3 Theta (5-7Hz) Beta (13-30Hz)</td>
<td>Awake No, white bright light is not effective in reducing theta and beta activities than ambient white light</td>
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</table>

**Night time-low intensity monochromatic blue light**

<table>
<thead>
<tr>
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<th>Time of intervention delivery within one 24hr cycle</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Subjective sleepiness measurement</th>
<th>Objective sleepiness measurement</th>
<th>Outcome of light intervention</th>
<th>Outcome of light intervention</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cajochen et al. 2005 [45]</td>
<td>Crossover WP = 1 wk Order of light treatment</td>
<td>Volunteers N = 10 Mean age: 25.9 yrs 0% female</td>
<td>2 lux dim light for 1.5hrs starting from 1800</td>
<td>NIGHTTIME (2130-2330) 2hrs/session</td>
<td>Monochromatic blue light = 460nm Monochromatic green light = 555nm</td>
<td>KSS, measured 5 times every 30mins Yes, blue light is</td>
<td>N/A</td>
<td>Skin conductor and rectal probe were used to collect temperature, heart</td>
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<tr>
<td>Citation</td>
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<td>Sample</td>
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<td>Sleep history 24 hrs prior to intervention</td>
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<tr>
<td>Lockley et al. 2006 [9]</td>
<td>RCT</td>
<td>Volunteers</td>
<td>1 night</td>
<td>photon density</td>
<td>photon density</td>
<td>effective in reducing subjective sleepiness than green light</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>rate, KSS and saliva</td>
</tr>
<tr>
<td></td>
<td>Random allocation to light treatment reported</td>
<td>Non-smokers</td>
<td>3hrs dark adaption (1930-2130)</td>
<td>not reported, but participants’ usual sleep-wake cycle is stated</td>
<td>Participants were wake for 13.5hrs before light treatment</td>
<td>photon density = 2.8 x 10^{13} photons/cm^2/s</td>
<td>photon density = 2.8 x 10^{13} photons/cm^2/s</td>
<td>Irradiance: 12.1 µW/cm^2</td>
<td>half peak band width: 10nm</td>
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<tr>
<td></td>
<td>Lab</td>
<td></td>
<td></td>
<td>Sleep restriction applied: No sleep for the 1st night, and 8hrs/night for the 2nd night before light treatment</td>
<td>Participants were awake for 4.75hrs prior to light intervention</td>
<td>Monochromatic blue light of 460nm</td>
<td>Monochromatic green light of 555nm</td>
<td>KSS, measured every hour for 7 times</td>
<td></td>
<td>Yes, blue light was effective in reducing subjective sleepiness than green light</td>
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<td></td>
<td>Sleep restriction applied: No sleep for the 1st night, and 8hrs/night for the 2nd night before light treatment</td>
<td>Participants were awake for 4.75hrs prior to light intervention</td>
<td>Monochromatic blue light of 460nm</td>
<td>Monochromatic green light of 555nm</td>
<td>KSS, measured every hour for 7 times</td>
<td></td>
<td>Yes, blue light was effective in reducing subjective sleepiness than green light</td>
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</tr>
<tr>
<td>Phipps et al. 2009 [38]</td>
<td>Crossover</td>
<td>Volunteers</td>
<td>&lt;3lux dim fluorescent light for 4.75hrs prior to the participant’s usual wake time</td>
<td>Sleep restriction applied: No sleep for the 1st night, and 8hrs/night for the 2nd night before light treatment</td>
<td>Participants were awake for 4.75hrs prior to light intervention</td>
<td>photon density = 2.8 x 10^{13} photons/cm^2/s</td>
<td>photon density = 2.8 x 10^{13} photons/cm^2/s</td>
<td>Irradiance: 12.1 µW/cm^2</td>
<td>half peak band width: 10nm</td>
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<td></td>
<td>Lab</td>
<td></td>
<td></td>
<td>Sleep restriction applied: No sleep for the 1st night, and 8hrs/night for the 2nd night before light treatment</td>
<td>Participants were awake for 4.75hrs prior to light intervention</td>
<td>Monochromatic blue light of 460nm</td>
<td>Monochromatic green light of 555nm</td>
<td>KSS, measured every hour for 7 times</td>
<td></td>
<td>Yes, blue light was effective in reducing subjective sleepiness than green light</td>
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<td>Sleep restriction applied: No sleep for the 1st night, and 8hrs/night for the 2nd night before light treatment</td>
<td>Participants were awake for 4.75hrs prior to light intervention</td>
<td>Monochromatic blue light of 460nm</td>
<td>Monochromatic green light of 555nm</td>
<td>KSS, measured every hour for 7 times</td>
<td></td>
<td>Yes, blue light was effective in reducing subjective sleepiness than green light</td>
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<tr>
<td>Citation</td>
<td>Study design Setting</td>
<td>Sample</td>
<td>Light condition for the adaption period</td>
<td>Sleep history within 1 day</td>
<td>Time of intervention delivery within one 24hr cycle</td>
<td>Intensity (lux) of intervention</td>
<td>Intensity (lux) of control</td>
<td>Subjective sleepiness measurement</td>
<td>Objective sleepiness measurement</td>
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<tr>
<td>Chellappa et al. 2011 [5]</td>
<td>counterbalanced lab</td>
<td>caffeine and alcohol use, No eye disease, No sleep disorder, No extreme chronotypes</td>
<td>(2300-0700)</td>
<td>Participants were awake for 17.5 hrs prior to light intervention</td>
<td>1 day</td>
<td>Irradiance: 2.05 to 2.07uw/cm², peak wavelength of 430 &amp; 620nm</td>
<td>Irradiance: 0.05 to 0.17uw/cm², half peak band width: 25nm</td>
<td>reducing subjective sleepiness than ambient white light (no difference)</td>
<td>reduced delta &amp; theta wave activities than ambient white light</td>
<td>reduced delta &amp; theta wave activities than ambient white light</td>
<td>No, blue light was not effective on alpha activities than ambient white light</td>
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<tr>
<td>Night time-low intensity blue enhanced white light</td>
<td>Crossover</td>
<td>Volunteers, N = 16, Mean age: 24.3 yrs, 0% female, Non-smokers, No medical, psychiatric and sleep disorders, No use of medications, and drug abuse, No excessive alcohol, caffeine use, No shift work and trans meridian flights in the past 1 mth, No extreme chronotypes, No poor sleep quality</td>
<td>&lt; 8lux dim light from 1800-1930 Darkness adaption from 1930-2130</td>
<td>N/A</td>
<td>Blue enriched white light: 40lux at eye level</td>
<td>White light: 40lux at eye level</td>
<td>Blue enriched white light: 40lux at eye level</td>
<td>White light: Fluorescent light</td>
<td>KSS, measured 3 times</td>
<td>Yes, 6500K light is effective in reducing subjective sleepiness than 25000K light</td>
<td>N/A</td>
<td>VAS + KSS + saliva sample &amp; cognitive test. Participants remained seated and gazed at the wall</td>
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<tr>
<td></td>
<td>WP = 1 wk</td>
<td>Order of light treatment, counterbalanced lab</td>
<td>(2130-2330hrs)</td>
<td>Usual sleep and wake schedule</td>
<td>1 night</td>
<td>Fluorescent light: CCT 6500K Peak wavelength: 435 nm</td>
<td>Fluorescent light: CCT 2500K Peak wavelength: 435nm</td>
<td>Greater input from 420-520nm band than the control as per Figure 2</td>
<td>Yes, 6500K light is effective in reducing subjective sleepiness than 25000K light</td>
<td>N/A</td>
<td>VAS + KSS + saliva sample &amp; cognitive test. Participants remained seated and gazed at the wall</td>
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<tr>
<td>Citation</td>
<td>Study design</td>
<td>Setting</td>
<td>Sample</td>
<td>Light condition for the adaption period</td>
<td>Sleep history 24 hrs prior to intervention</td>
<td>Time of intervention delivery within one 24hr cycle</td>
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<tr>
<td>Cajochen et al. 2011 [6]</td>
<td>Crossover</td>
<td>Lab</td>
<td>Volunteers N = 13</td>
<td>30mins dark adaption plus 4hrs dim light of &lt;4lux red light prior to their usual bed time (around 2300hrs)</td>
<td>Sleep time for the night before light treatment was not reported, but was the same as their usual sleep wake time</td>
<td>NIGHTTIME (2000-0100) 5hrs/session 1 night</td>
<td>LED illuminated HP LP2480zx screen</td>
<td>Similar spectral distribution from 500nm to 780nm to the LED illuminated screen. Greater output within the range of 410-500nm</td>
<td>Fluorescent lamp illuminated HP LP2475w screen</td>
<td>KSS, measured every 30mins</td>
<td>SEM incidents</td>
<td></td>
</tr>
<tr>
<td>Chang AM et al. 2015 [46]</td>
<td>Crossover</td>
<td>Lab</td>
<td>Volunteers N = 12</td>
<td>Not reported</td>
<td>Nil sleep restriction</td>
<td>NIGHTTIME (1800-2200) 4hrs/session 5 nights</td>
<td>Blue intense light + ambient room light 31.73lux</td>
<td>Ambient room light 0.91lux</td>
<td>Fluorescent Peak</td>
<td>KSS, measured 1hr before bed time every night (once/night)</td>
<td>Yes, reading ebooks was effective in reducing subjective sleepiness than reading a physical book</td>
<td>N/A</td>
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</table>

For the first 3hrs reading, participants were seated to read. Then, participants had a 15mins break, where they could walk around and prepare for bed, before returning to read in bed.
<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design</th>
<th>Setting</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
<th>Sleep history 24 hrs prior to intervention</th>
<th>Time of intervention delivery within one 24hr cycle</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Subjective sleepiness measurement</th>
<th>Objective sleepiness measurement</th>
<th>Outcome of light intervention</th>
<th>Outcome of light intervention</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rangtell et al. 2016 [47]</td>
<td>Crossover</td>
<td>Lab</td>
<td>Volunteers</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2100-2300) 2hrs/session 1 night</td>
<td>wavelength = 452nm as per Figure 4</td>
<td>wavelength = 612nm as per Figure 4</td>
<td>Physical book reading – magician 67.3lux</td>
<td>No, reading an ebook does not reduce subjective sleepiness (no difference)</td>
<td>N/A</td>
<td>“Magician” was the ebook</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WP = 6 days</td>
<td></td>
<td>N = 14</td>
<td>Age: not reported</td>
<td>500lux for 6.5hrs before light treatment</td>
<td>Participants were likely to have been awake for 13hrs prior to light intervention</td>
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<td></td>
<td>Randomisation of light treatment order reported</td>
<td></td>
<td>42.0% female</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2000-0800) 12hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Lab</td>
<td></td>
<td>% female unknown</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2100-2300) 2hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
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<td></td>
<td></td>
<td></td>
<td>Normal weight, right handed</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2100-2300) 2hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>No use of drugs, nicotine, and travelling of time zone within the month before</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2100-2300) 2hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>No psychiatric, neurologic, hormonal, metabolic, sleep disorders</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2100-2300) 2hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>No eye conditions</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2100-2300) 2hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Chronotype = 16.8 ± 2.8 could have included extremes</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2100-2300) 2hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Night time-high intensity blue filtered white light**

<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design</th>
<th>Setting</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
<th>Sleep history 24 hrs prior to intervention</th>
<th>Time of intervention delivery within one 24hr cycle</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Subjective sleepiness measurement</th>
<th>Objective sleepiness measurement</th>
<th>Outcome of light intervention</th>
<th>Outcome of light intervention</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rahman et al. 2011 [49]</td>
<td>Crossover</td>
<td></td>
<td>Volunteers</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2000-0800) 12hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>WP = likely to be 1 wk, Random allocation to light treatment order</td>
<td></td>
<td>N = 12</td>
<td>Mean age: 25.8 yrs</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2000-0800) 12hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
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<td></td>
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<td></td>
<td>42.0% female</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2000-0800) 12hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
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<td></td>
<td></td>
<td></td>
<td>No medication except contraceptives</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2000-0800) 12hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
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<td></td>
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<td></td>
<td>Maintained in the same room for 1hr before light treatment to mimic real shift work</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2000-0800) 12hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
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<td></td>
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<td></td>
<td>Participants were asked to maintain a</td>
<td>No impaired vision.</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (2000-0800) 12hrs/session 1 night</td>
<td>1.480nm filtered fluorescent of 430.43lux</td>
<td></td>
<td>SST, measured every 30mins for 5 times</td>
<td>N/A</td>
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<tr>
<td>Citation</td>
<td>Study design</td>
<td>Setting</td>
<td>Sample</td>
<td>Light condition for the adaption period</td>
<td>Sleep history 24 hrs prior to intervention</td>
<td>Time of intervention delivery within one 24hr cycle</td>
<td>Intensity (lux) of intervention</td>
<td>Intensity (lux) of control</td>
<td>Subjective sleepiness measurement</td>
<td>Objective sleepiness measurement</td>
<td>Outcome of light intervention</td>
<td>Outcome of light intervention</td>
<td>Participants' activities during sleepiness assessment</td>
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<tr>
<td>Van der Werken et al. 2013 [48]</td>
<td>Crossover WP = at least 1wk random allocation to order of treatment reported • Lab</td>
<td>Volunteers • N = 33 • Mean age: 22.6yrs • 0% female • Non-smokers • No excessive use of alcohol, caffeine • No use of medications No sleep disorders • No somatic diseases • No depression • No chronic disease • No visual impairment • No night shifts within the last 3mths • No travelling across time zones within the 1mth</td>
<td>&lt; 5lux for 2hrs before light treatment</td>
<td>Not reported</td>
<td>NIGHTTIME (2300-0700) 8hrs/session 2 nights</td>
<td>&lt;530nm filtered fluorescent white light from Phillips TL-D 36W/830 193lux</td>
<td>Full spectrum fluorescent white light from Phillips TL-D 36W/830 256lux</td>
<td>KSS, measured 8 times</td>
<td>N/A</td>
<td>Saliva, urine sample, and skin temperature, KSS measurements</td>
<td>Played board games as a group when not completing tests</td>
<td>No, short-wavelength attenuated white light is not effective in reducing subjective sleepiness than full spectrum white light (no difference)</td>
<td></td>
</tr>
<tr>
<td>Citation</td>
<td>Study design</td>
<td>Setting</td>
<td>Sample</td>
<td>Light condition for the adaption period</td>
<td>Sleep history 24 hrs prior to intervention</td>
<td>Time of intervention delivery within one 24hr cycle</td>
<td>Intensity (lux) of intervention</td>
<td>Intensity (lux) of control</td>
<td>Subjective sleepiness measurement</td>
<td>Objective sleepiness measurement</td>
<td>Participants’ activities during sleepiness assessment</td>
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<tr>
<td>Sasseville et al. 2015 [36]</td>
<td>RCT</td>
<td>Lab</td>
<td>Volunteers, N = 20, Mean age: 25.9 yrs, 55% female, No mental and physical illness, No use of medication except contraceptives, No report of chronotypes</td>
<td>&lt; 5lux</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (0300-0330) 30 mins/session 1 night</td>
<td>intervention&lt;br&gt;Full spectrum&lt;br&gt;White light&lt;br&gt;1150lux</td>
<td>control&lt;br&gt;White light&lt;br&gt;1420 lux</td>
<td>VAS-alertness KSS-sleepiness, measured upon light turned off (once only)</td>
<td>N/A</td>
<td>Alertness, energy, mood and sleepiness + Conner’s objective performance test</td>
<td></td>
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</tr>
<tr>
<td>Lavoie et al. 2003 [50]</td>
<td>Crossover</td>
<td>Lab</td>
<td>Volunteers, N = 14, Mean age: 26.1 yrs, 57.1% female, Non-smokers, No use of drugs and medications, No caffeine during and on the day before experiment, In good physical and mental health, No sleep disorder, No history of psychiatric and neurological disorders, No shift work or across</td>
<td>&lt; 15lux from 1900 to 0030</td>
<td>Nil sleep restriction</td>
<td>NIGHTIME (0030-0430) 4hrs/session 1 night</td>
<td>intervention&lt;br&gt;No further information available</td>
<td>Red light&lt;br&gt;4-24lux</td>
<td>VAS, measured twice&lt;br&gt;Yes, white bright light was effective in reducing Beta-1 activities&lt;br&gt;Yes, white bright light was effective in reducing Beta-1 activities</td>
<td>Beta 1 (16-24Hz) measured twice&lt;br&gt;Cognitive tasks, EEG, KSS, KDTs and skin temperature measurements</td>
<td>Cognitive tasks, EEG, KSS, KDTs and skin temperature measurements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citation</td>
<td>Study design</td>
<td>Setting</td>
<td>Sample</td>
<td>Light condition for the adaption period</td>
<td>Sleep history 24 hrs prior to intervention</td>
<td>Time of intervention delivery within one 24hr cycle</td>
<td>Intensity (lux) of intervention</td>
<td>Intensity (lux) of control</td>
<td>Subjective sleepiness measurement</td>
<td>Objective sleepiness measurement</td>
<td>Participants’ activities during sleepiness assessment</td>
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<tr>
<td>Yokoi et al. 2003 [28]</td>
<td>Crossover</td>
<td>Lab</td>
<td>Volunteers</td>
<td>Nil sleep restriction</td>
<td>1 night</td>
<td>NIGHTTIME (2110-0430)</td>
<td>White light 2800lux Fluorescent</td>
<td>White light 120lux fluorescent</td>
<td>Kwansei Gakuin sleepiness scale (KGS), measured 4 times, every 2hrs No, the intervention light was not effective in reducing average subjective sleepiness at rest and working conditions, but the sleep onset was earlier in the control group. Alpha (8.0566-13.183Hz) Theta (4.1504-8.0566Hz), measured every 2hrs Yes, at rest: intervention light significantly reduced objective sleepiness than dim light because alpha waves were higher in BL condition than DL condition, Fig 1 &amp; 2, indicating less sleepiness No, during mental task, there was no difference in theta or alpha wave activities between intervention and control light</td>
<td>KGS, EEG, mental tasks</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Van der Lely et al. 2015 [51]</td>
<td>Crossover</td>
<td>ambulatory phase is 1wk+</td>
<td>Volunteers</td>
<td>&lt;150lux for the 2 hours before light exposure (1930 to 2110)</td>
<td>Regular sleep and wake schedule</td>
<td>Participants were awake for 13hrs prior to light intervention</td>
<td>White light 2800lux Fluorescent</td>
<td>White light 120lux fluorescent</td>
<td>KSS, measured 6 times EEG correlates Frequency bands not reported, only</td>
<td>Participants completed psychomotor</td>
<td>Night time-others</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Citation</strong></td>
<td><strong>Study design</strong></td>
<td><strong>Setting</strong></td>
<td><strong>Sample</strong></td>
<td><strong>Light condition for the adaption period</strong></td>
<td><strong>Sleep history 24 hrs prior to intervention</strong></td>
<td><strong>Time of intervention delivery within one 24hr cycle</strong></td>
<td><strong>Intensity (lux) of intervention</strong></td>
<td><strong>Intensity (lux) of control</strong></td>
<td><strong>Subjective sleepiness measurement</strong></td>
<td><strong>Objective sleepiness measurement</strong></td>
<td><strong>Outcome of light intervention</strong></td>
<td><strong>Outcome of light intervention</strong></td>
<td><strong>Activities during sleepiness assessment</strong></td>
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<tr>
<td>laboratory phase</td>
<td>1 day</td>
<td>WP = 1 wk</td>
<td>• 0% female</td>
<td>• Good somatic and mental health</td>
<td>• Average use of 2.5hrs per evening in front of media screen</td>
<td>• No somatic and psychogenic origin</td>
<td>• No sleep disorder</td>
<td>• No drug or alcohol dependency</td>
<td>• No transmeridian travel in past month (detailed in the supplementary material)</td>
<td>• Moderate to extreme evening types</td>
<td>by dark adaption for 0.5hr before experimental light exposure</td>
<td>Regular sleep wake schedule maintained 3 days before the lab</td>
<td>Light exposure in the lab started 3 hrs before one’s habitual bed time, so participants were awake for 13hrs prior to intervention</td>
</tr>
</tbody>
</table>

Captions: BB = Blue blocker; CCT = Correlated colour temperature; EEG = Electroencephalography; EOG = Electrooculogram; KDT = Karolinska drowsiness test; KGS = Kwansei Gakuin sleepiness; KSS = Karolinska sleepiness scale; LDST = Letter digit substitution test; MAT = Multi-attribute task; NC = Necker cube pattern control task; NSAID = Nonsteroidal anti-inflammatory drug; PVT = Performance vigilance test; SEM = Slow eye movement; VAS = visual analogue scale; WP = Washout period
Table 2: Studies examining the POST illuminance alerting effect of light (N = 14)

<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design</th>
<th>Sample</th>
<th>Light condition for the adaptation period</th>
<th>Sleep history 24 hrs prior to intervention</th>
<th>Light condition after completion of intervention within 24hrs</th>
<th>Light condition after completion of intervention on 24hrs after</th>
<th>Time of delivering within one 24hr cycle</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Measurement of subjective sleepiness/time period relevant to the completion of light intervention</th>
<th>Measurement of objective sleepiness/time period relevant to the completion of light intervention</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lavoie et al. 2003 [50]</td>
<td>Crossover</td>
<td>Volunteers</td>
<td>&lt; 15lux from 1900 to 0030</td>
<td>Nil sleep restriction</td>
<td>&lt; 15lux</td>
<td>N/A</td>
<td>NIGHTIME (0030-0430)</td>
<td>2300 to 4700lux</td>
<td>4-24lux</td>
<td>VAS, at 1hr after illuminance (once only)</td>
<td>No, white bright light was not effective in reducing subjective sleepiness compared to red light</td>
<td>Cognitive tasks, EEG, KSS, KDT and skin temperature measurements</td>
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<tr>
<td></td>
<td>WP = 7-10 days</td>
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<td>4hrs/session</td>
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<td></td>
<td>Order of light treatment counterbalanced</td>
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<td>1 night</td>
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<td></td>
<td>Lab</td>
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<tr>
<td>Phipps-Nelson et al. 2003 [10]</td>
<td>RCT</td>
<td>Volunteers</td>
<td>dim light of &lt;5lux from awakening to 1200hrs</td>
<td>Sleep restriction protocol applied: 5hrs/night for 2 nights before light intervention</td>
<td>Not directly reported, likely to be dim light of &lt;5lux</td>
<td>N/A</td>
<td>DAYTIME (1200-1700)</td>
<td>White light</td>
<td>White light</td>
<td>KSS, 4hrs after illuminance</td>
<td>No, intervention light was not effective in reducing MWT, beta-1 or theta-alpha activities compared to red dim light</td>
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<td></td>
<td>Random allocation reported</td>
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<td>5hrs per session</td>
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<td></td>
<td>Lab – modified constant routine</td>
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<td>1 day</td>
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<tr>
<td>Citation</td>
<td>Study design Setting</td>
<td>Sample</td>
<td>Light condition for the adaption period</td>
<td>Sleep history 24 hrs prior to intervention</td>
<td>Light condition after completion of intervention within 24hrs</td>
<td>Light condition after completion of intervention on 24hrs after</td>
<td>Time of delivering within one 24hr cycle</td>
<td># of 24hr cycle repeated</td>
<td>Intensity (lux) of intervention</td>
<td>Intensity (lux) of control</td>
<td>Measurement of subjective sleepiness/time period relevant to the completion of light intervention</td>
<td>Measurement of objective sleepiness/time period relevant to the completion of light intervention</td>
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<tr>
<td>Munch et al. 2012 [41]</td>
<td>Crossover</td>
<td>Lab</td>
<td>Daylight exposure on the communal from home to the lab is likely</td>
<td>Participants were awake for 6hrs before light intervention</td>
<td>Daylight exposure on the communal from home to the lab is likely</td>
<td>White light 1000lux at eye level</td>
<td>DAYTIME (1200-1800)</td>
<td>1 day</td>
<td>White light</td>
<td>White light 1000lux at eye level</td>
<td>Fluorescent CCT 3700K</td>
<td>KSS, 2hrs after illuminance</td>
</tr>
<tr>
<td>Leichtf</td>
<td>Crossover</td>
<td></td>
<td>Daylight ±fluorescent light to maintain illuminance at above 1000lux</td>
<td>Participants were awake for 4-5hrs prior to light intervention</td>
<td>Daylight ±fluorescent light to maintain illuminance at above 1000lux</td>
<td>White light 1000lux at eye level</td>
<td>DAYTIME (1200-1800)</td>
<td>1 day</td>
<td>White light</td>
<td>White light 1000lux at eye level</td>
<td>Fluorescent CCT 3700K</td>
<td>KSS, 2hrs after illuminance</td>
</tr>
</tbody>
</table>

- Participants’ activities during sleepiness assessment:
  - Consume <5 standard units of alcohol/wk
  - Good physical and psychological health
  - No poor sleep quality
  - No shift work and across time zone travelling in the last 3mths
  - No extreme chronotypes
  - Volunteers
  - N=29
  - Mean age: 23.6 yrs
  - 41.4% female
  - Non-smokers
  - Moderate consumption of caffeine and alcohol generally; refrain from caffeine and alcohol on the study day
  - No current regular medication
  - No medical or psychiatric disorders
  - No shift work or cross time zone travelling in past 2 mths
  - 28 normal chronotype, 1 morning type
  - Volunteers
  - 400lux for 400lux N/A DAYTIME
  - 1000lux at eye level 6hrs/session 1 day
  - 400lux for 400lux N/A DAYTIME
  - 1000lux at eye level 6hrs/session 1 day
  - Nil sleep restriction N/A
  - Participants kept regular sleep and wake schedule
  - Participants were awake for 4-5hrs prior to light intervention
  - < 6lux dim light N/A
  - White light VAS, 2 mins after N/A Under dim
  - White light VAS, 2 mins after N/A Under dim
  - White light VAS, 2 mins after N/A Under dim
  - White light VAS, 2 mins after N/A Under dim

- Evidence:
  - morning light exposure was not controlled
  - Participants were awake for 6hrs before light intervention
  - Participants were awake for 4-5hrs prior to light intervention
  - < 6lux dim light
  - White light 1000lux at eye level
  - Fluorescent CCT 3700K
  - White light 176lux at eye level
  - Fluorescent CCT 3700K
  - VAS, 2 mins after
  - N/A

- Note: participants in the office light group had earlier onset of sleepiness compared to the daylight group.
<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
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<th>Time of delivering within one 24hr cycle</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Measurement of subjective sleepiness/time period relevant to the completion of light intervention</th>
<th>Measurement of objective sleepiness/time period relevant to the completion of light intervention</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ried et al. 2015</td>
<td>• RCT</td>
<td>• Volunteers</td>
<td>• Amber light exposure for 30mins (0945-1015) in a darkened room</td>
<td>• Daylight exposure was likely on the communal from home to the lab</td>
<td>• Participants were awake for at least 1hr prior to light intervention</td>
<td>• Not reported</td>
<td>0740-0810</td>
<td>3000lux</td>
<td>400lux</td>
<td>No, blue light is not effective in reducing subjective sleepiness compared to amber light (no difference)</td>
<td>N/A</td>
<td>light condition, no cognitive task involved</td>
</tr>
<tr>
<td></td>
<td>• RCT</td>
<td>• Volunteers</td>
<td>• Blue light = 469nm</td>
<td>• Amaranth light = 578nm</td>
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<td>• Volunteers</td>
<td>• Measure of subjective sleepiness/time period relevant to the completion of light intervention</td>
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<td># of 24hr cycle repeated</td>
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<tr>
<td>2016 [35]</td>
<td>allocation to light treatment reported</td>
<td>Lab</td>
<td>• Age range: 18-31 yrs&lt;br&gt;• 52.7% female&lt;br&gt;• Non-smokers or no drug user in the past 12mths&lt;br&gt;• Caffeine consumption &lt; 300mg/day in the past 12mths&lt;br&gt;• Alcohol consumption &lt; 14U/wk in the past 12mths&lt;br&gt;• No psychiatric or chronic illness&lt;br&gt;• Not on regular medications&lt;br&gt;• No colour blindness&lt;br&gt;• No sleep disorder&lt;br&gt;• No shift work in the past 2yrs&lt;br&gt;• No travelling across time zones for no more than 2 times in the last 3mths&lt;br&gt;• No extreme chronotypes</td>
<td>fluorescent light for 3.25hrs from waking prior to light treatment. Participants were awake for 3.25hrs prior to light treatment</td>
<td>applied: 5hrs/night for night 1, and 3hrs/night for night 2 before light treatment</td>
<td>light for the 3 hours post experimental light exposure waking time</td>
<td>3hrs/session for 1 session</td>
<td>1 day</td>
<td>1</td>
<td>Melbourne = 458nm; Boston = 480nm&lt;br&gt;photons density = 2.8 x 10^13 photons/cm^2/s at Melbourne site, 8.4 x 10^15 photons/cm^2/s at Boston site&lt;br&gt;IRRADIANCE: 13.24µW/cm^2 Melbourne; 34.06µW/cm^2 Boston&lt;br&gt;pupils dilated</td>
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<td></td>
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<tr>
<td>2017 [42]</td>
<td>Crossover&lt;br&gt;WP ≥ 1wk&lt;br&gt;Order of light treatment counterbalanced</td>
<td>Lab</td>
<td>• Volunteers&lt;br&gt;N = 19&lt;br&gt;• Mean age: 22.8 yrs&lt;br&gt;• 31.6% female&lt;br&gt;• No sleep disorder&lt;br&gt;• No use of sleep&lt;br&gt;Sleep deprivation group: 35lux (incandescent) for 6hrs&lt;br&gt;Sleep restriction protocol&lt;br&gt;1.5lux at when performing simulated driving test&lt;br&gt;DAYTIME (0600-0800)&lt;br&gt;45mins/session</td>
<td>White light&lt;br&gt;5600lux at eye level&lt;br&gt;Fluorescent&lt;br&gt;44mins after illuminance (immediately after driving simulation)&lt;br&gt;yes, light</td>
<td>White light&lt;br&gt;&lt;50lux at eye level&lt;br&gt;Incandescent&lt;br&gt;yes, light</td>
<td>KSS, 44mins after illuminance&lt;br&gt;(immediately after driving simulation)</td>
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</tbody>
</table>
**Citation** | Study design | Sample | Light condition for the adaption period | Sleep history | Light condition after completion of intervention | Light condition after completion of intervention within 24hrs | Time of delivering within one 24hr cycle | # of 24hr cycle repeated | Intensity (lux) of intervention | Intensity (lux) of control | Measurement of objective sleepiness/time period relevant to the completion of light intervention | Measurement of objective sleepiness/time period relevant to the completion of light intervention | Participants' activities during sleepiness assessment
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
Cajochen et al. 2005 [45] | Crossover | Volunteers | N = 10  | Mean age: 25.9 yrs | 0% female | Non-smokers | No caffeine or alcohol within 1 week before the study | No medical, psychiatric, and sleep disorders | 2 lux dim light for 1.5hrs from 1800-1930 | Dark adaption from 1930-2130 | Participants were wake for sleep time for the night before light treatment is not reported, but participants' usual sleep-wake cycle is stated | 2lux | N/A | NIGHTTIME (2130-2330)  | 2hrs/session | 1 night | Photon density = 2.8 x 10^12 photons/cm²/s  | Photon density = 2.8 x 10^11 photons/cm²/s  | Irradiance: 12.1µW/cm²  | Irradiance: 10.05µW/cm²  | Monochromatic blue light = 460nm  | Monochromatic green light = 555nm  | KSS, over the 1.5hrs after illumination, measured 4 times | N/A | KSS assessment, saliva collection, continuous rectal temperature monitoring and skin surface monitoring, continuous heart rate

### Light condition for the adaption period

- **Rested group:** Various daylight (dawn light) for 45mins from usual wake up time to arrival at the lab
- **Rested group:** Nil sleep restriction.

### Sleep history

- Participants were awake for 22hrs before light treatment.

### Light condition after completion of intervention

- Participants were awake for 45mins before light treatment.

### Time of delivering light intervention

- 1 day
- Rested group: Daytime (from awakening) 45mins/session

### Intensity (lux) of control

- Light intensity: 5000K Sunbox K10 model, Sunbox USA + 4100K SADelite, Lamp Northern Lights Canada

### Outcome of light intervention

- Light intervention was effective in reducing subjective sleepiness

### Measurement of objective sleepiness/time period relevant to the completion of light intervention

- Note: light intervention was not effective immediately upon the completion of light exposure

### Participants' activities during sleepiness assessment

- Laboratory – simulated driving session
- No use of NSAID
- Healthy
- No shift work and travelling across time zones in the past 3mths
- No extreme chronotype

### Sleepiness assessment

- KSS, over the 1.5hrs after illumination, measured 4 times
- No, blue light was not effective in reducing subjective sleepiness compared to green light
- Note: blue light was effective during

### Light exposure

- 5000K Sunbox K10 model, Sunbox USA + 4100K SADelite, Lamp Northern Lights Canada
- Monochromatic blue light = 460nm  Photon density = 2.8 x 10^12 photons/cm²/s  Irradiance: 12.1µW/cm²
- Monochromatic green light = 555nm  Photon density = 2.8 x 10^11 photons/cm²/s  Irradiance: 10.05µW/cm²

### Night time- post-illuminance alertness within 24hrs before a sleep episode

- No, blue light was not effective in reducing subjective sleepiness compared to green light
- Note: blue light was effective during
<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design Setting</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
<th>Sleep history</th>
<th>Light condition after completion of intervention within 24hrs</th>
<th>Light condition after completion of intervention within 24hrs</th>
<th>Time of delivering light within one 24hr cycle</th>
<th># of 24hr cycle repeated</th>
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<th>Participants' activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phipps-Nelson et al., 2009 [38]</td>
<td>Crossover, WP = at least 4 wks, Order of light treatment counterbalanced, Lab</td>
<td>Volunteers: N = 8, Mean age: 32.1 yrs, 37.3% female, Low to moderate caffeine and alcohol use, No eye disease, No sleep disorder, No extreme chronotypes</td>
<td>&lt; 5lux, then &lt; 1 lux from 1200-2030hrs in the lab</td>
<td>13.5hrs before light treatment</td>
<td>Nil sleep restriction</td>
<td>Regular sleep wake cycle (2300-0700)</td>
<td>Participants were awake for 17.5 hrs prior to light intervention</td>
<td>NIGHTIME (2330-0530)</td>
<td>6hrs/session</td>
<td>1 day</td>
<td>Blue light = 460nm, 1.12-1.15lux</td>
<td>Ambient white light, 0.02-0.2lux</td>
<td>No, blue light was not effective in reducing subjective sleepiness compared to ambient light</td>
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<td></td>
<td>No, blue light was not effective in reducing subjective sleepiness compared to ambient light</td>
<td>No, blue light was not effective on alpha activities compared to ambient white light</td>
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<td></td>
<td>Note: no difference during light exposure either</td>
<td>Simulated driving test, PVT, KSS and saliva sample tests</td>
</tr>
</tbody>
</table>

**Note:**
- No difference during light exposure either
- Delta (1-4.5Hz) Theta (4.5-8Hz) at 3hrs after illuminance
- Simulated driving test, PVT, KSS and saliva sample tests
<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design Setting</th>
<th>Sample</th>
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<th>Sleep history 24 hrs prior to intervention</th>
<th>Light condition after completion of intervention within 24hrs</th>
<th>Light condition after completion of intervention on 24hrs after</th>
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<th>Outcome of light intervention</th>
<th>Participants’ activities during sleepiness assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kacharni et al. 2011 [54]</td>
<td>Crossover • WP = 6 days • Randomisation of order reported • Field - metal production plant</td>
<td>Participants were working on evening shifts from 1400-2200</td>
<td>Not reported</td>
<td>Not reported</td>
<td>N/A</td>
<td>NIGHTIME (2200-2215hrs) (2400-2415hrs) (0200-0215hrs) (0400-0415hrs)</td>
<td>Fluorescent</td>
<td>Fluorescent</td>
<td>White light</td>
<td>White light</td>
<td>2500-3000lux</td>
<td>300lux</td>
<td>SSS, measured 45mins after illuminance</td>
<td>N/A</td>
</tr>
<tr>
<td>Chang et al. 2015 [46]</td>
<td>Crossover • WP not reported • Order to light treatment randomised • Lab</td>
<td>Participants were likely to have been awake for 10hrs prior to light intervention</td>
<td>Nil sleep restriction</td>
<td>After light exposure &amp; before sleep: Darkness for PSG assessment &lt; Blux for KSS assessment</td>
<td>After 1 night's sleep: &lt; Blux for KSS assessment</td>
<td>NIGHTIME (1800-2200)</td>
<td>Fluorescent</td>
<td>Fluorescent</td>
<td>Blue intense light + ambient room light</td>
<td>Ambient room light</td>
<td>0.91lux</td>
<td>KSS, measured 5-6 times for the one hour after waking up</td>
<td>Delta/theta (1.0-7.5Hz), no differentiation was made between the 2 bands</td>
<td>Awake</td>
</tr>
</tbody>
</table>

Night time-post-illuminance alertness within 24hrs, but after a sleep episode

- Nil sleep restriction
- Participants were likely to have been awake for 10hrs prior to light intervention
- After light exposure & before sleep: Darkness for PSG assessment < Blux for KSS assessment
- After 1 night's sleep: < Blux for KSS assessment

- Blue intense light + ambient room light
- Ambient room light
- Delta/theta (1.0-7.5Hz), no differentiation was made between the 2 bands
- Awake
- Yes, reading ebooks was effective in reducing sleepiness (less delta/theta) compared to reading a physical book.
<table>
<thead>
<tr>
<th>Citation</th>
<th>Study design</th>
<th>Setting</th>
<th>Sample</th>
<th>Light condition for the adaption period</th>
<th>Sleep history 24 hrs prior to intervention</th>
<th>Light condition after completion of intervention within 24hrs</th>
<th>Light condition after completion of intervention 24hrs after</th>
<th>Time of delivering within one 24hr cycle</th>
<th>Intensity (lux) of intervention</th>
<th>Intensity (lux) of control</th>
<th>Measurement of subjective sleepiness/time period relevant to the completion of light intervention</th>
<th>Measurement of objective sleepiness/time period relevant to the completion of light intervention</th>
<th>Outcome of light intervention</th>
<th>Participants' activities during sleepiness assessment</th>
</tr>
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<tbody>
<tr>
<td>Rangtil et al. 2016 [47]</td>
<td>Crossover</td>
<td>WP = 6 days</td>
<td>Lab</td>
<td>Volunteers</td>
<td>Maintained a fixed 8hr (10pm-6am) within 3wks before the study</td>
<td>No report of chronotypes</td>
<td>500lux for 6.5hrs before light treatment</td>
<td>Nil sleep restriction</td>
<td>After light exposure &amp; before sleep: Darkness for PSG assessment (asleep)</td>
<td>N/A</td>
<td>NIGHTIME (2100-2300) 2hrs/session</td>
<td>Reading on an electronic device</td>
<td>102 lux</td>
<td>Physical book reading</td>
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<td></td>
<td></td>
<td></td>
<td>1 night</td>
<td>102 lux</td>
<td>Peak wavelength = 458nm as per Figure 3</td>
<td>Has twice more intensity of 466-477nm compared to the control</td>
<td>CCT 2674K</td>
</tr>
<tr>
<td>Cita</td>
<td>Study design</td>
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<tr>
<td>Thessin g et al. 1994 [52] experiment 1</td>
<td>RCT</td>
<td>Volunteers</td>
<td>N = 20</td>
<td>Mean age: 21 yrs</td>
<td>63.3% female</td>
<td>Non-smokers</td>
<td>Free of active medical or psychological illness or sleep complaints.</td>
<td>No extreme photosensitivity</td>
<td>No night work in the last 3mths</td>
<td>No extreme chronotypes</td>
<td>Nil sleep restriction</td>
<td>Regular sleep and wake schedule</td>
<td>Participants were awake for 16hrs prior to light intervention</td>
<td>&lt;300 lux for 4hrs from 0400-0800 on the night of light treatment</td>
</tr>
<tr>
<td>Thessin g et al. 1994 [52] experiment 2</td>
<td>RCT</td>
<td>Volunteers</td>
<td>N = 20</td>
<td>Mean age: 21 yrs</td>
<td>63.3% female</td>
<td>Non-smokers</td>
<td>Free of active medical or psychological illness or sleep complaints.</td>
<td>No extreme photosensitivity</td>
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<tr>
<td>Horowitz et al. 2001 [53]</td>
<td>RCT</td>
<td>Volunteers</td>
<td>&lt; 8lux dim light for 6hrs from 1700-2300</td>
<td>Nil sleep restriction</td>
<td>&lt; 8lux dim light, which is the light condition for the 38 hr constant routine</td>
<td>N/A</td>
<td>NIGHTIME (2300-0500)</td>
<td>White light 2500lux at the gaze</td>
<td>White light 150lux at the gaze</td>
<td>VAS, measured at 24hrs &amp; 48hrs after illumination under constant routine</td>
<td>N/A</td>
<td>Yes, the bright light was effective in reduced subjective sleepiness compared to room light</td>
<td>Constant routine</td>
<td></td>
</tr>
</tbody>
</table>

Captions: BL = Bright light; CCT = Correlated colour temperature; EEG = Electroencephalography; KDT = Karolinska drowsiness test; KSS = Karolinska sleepiness scale; MSLT= Multiple sleep latency test; MWT= Maintenance of wakefulness test; N/A = not applicable; NSAID = Nonsteroidal anti-inflammatory drugs; PSG = Polysomnography; PVT= Performance vigilance test; REM = Rapid eye movement; SSS = Stanford sleepiness scale; SWA = Slow wave activity; VAS= Visual analogue scale
1040 returns in total
After excluding the duplicates, 864 references left

121 potentially eligible articles for further screening

Screening of the reference list of the 25 reviews generated
n=5 articles

126 potentially eligible articles for further screening

Total exclusion: n = 743
• Manually identified duplicates: n = 82
• Thesis n = 2, of which publications were included under potentially eligible
• Conference abstract: n = 3
• Editorial: n = 1
• Handbook: n = 2
• Single case study: n = 4
• Review papers: n = 25
• Irrelevant to light and sleepiness: n = 547
• Studies not having a sleepiness measure: n = 2
• Studies with elderly people: n = 4
• People with excessive sleep deprivation (over 24 hrs), phase delay disorder: n = 10
• Patients with brain injury: n = 7
• People with neurological condition (dementia & PD): n = 10
• People with mental illness: n = 11
• People with other conditions: n = 13
• Patients with cataract surgery: n = 5
• Full text could not be retrieved: n = 1
• Not human research: n = 13
• Not comparable with other studies (continuous vs flashing): n = 1

78 potentially eligible articles were coded

Total exclusion: n = 50
• Ineligible study design: n = 12
• Unable to determine the independent alerting effect of light or using darkness as the control: n = 11
• Duplication: n = 3
• Conference paper: n = 1
• No sleepiness measure: n = 1
• Unable to differentiate during & after illuminance alerting effect: n = 1
• Illegitimate comparison of the time of delivery of bright light on levels of alertness: n = 1
• Failure to report allocation methods: n = 6
• Failure to report light source: n = 13
• Unclear experimental procedure: n = 1

28 articles included for review

Total exclusion: n = 48
• Studies that were irrelevant to the topic: n = 10
• Duplicate: n = 7
• Conference abstracts (unable to locate): n = 9
• Brief communication (unable to locate): n = 1
• Darkness as the control: n = 1
• Ineligible study design: n = 4
• No measurement of sleepiness/alertness: n = 2
• Older people with/without sleep complaint: n = 3
• People significantly sleep deprived: n = 1
• People with waking up problems: n = 1
• Totally blind people: n = 1
• Review paper: n = 1 (this one is not included in the above 18 reviews)
• Bright light is not an independent experiment condition: n = 1
• Written in Japanese: n = 1
• Not human research: n = 1
• Not comparable to other studies: n = 4

Figure 1 PRISMA flowchart for screening of literature
Figure 2 Assessment of risk of bias for RCTs (N = 8)

RCT = Randomised controlled trials
Figure 3 Assessment of risk of bias for crossover studies (N=20)

- Use of paired analysis (yes/no)
- Availability of complete dataset (yes/no)
- Assessment of carryover effect (yes/no)
- Selective reporting bias
- Bias due to incomplete data (objective sleepiness)
- Bias due to incomplete data (subjective sleepiness)
- Attrition bias
- Detection bias (objective sleepiness)
- Performance bias (subjective sleepiness)
- Selection bias-allocation concealment
- Selection bias-random sequence generation

Legend:
- low/yes
- high/no
- unclear
- non-applicable