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Circadian-effective light and its impact on alertness in office workers

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A field study was conducted at two U.S. federal government office sites and two U.S. embassies to demonstrate whether circadian-effective lighting (providing circadian stimulus (CS) values of CS $\geq$ 0.3) could be installed in office buildings, and to determine whether this lighting intervention would reduce sleepiness and increase alertness, vitality and energy in office workers while at work. Desktop and/or overhead luminaires provided circadian-effective lighting at participants' eyes during a two-day intervention. A pendant-mounted Daysimeter device was used to measure participant-specific CS values during the baseline and the intervention days. Participants also completed questionnaires inquiring about sleep habits, stress and subjective feelings of vitality and energy. The Daysimeter data showed that participants were exposed to significantly higher amounts of circadian-effective light while at work during the two intervention days compared to the baseline day. Self-reported sleepiness scores were significantly reduced during the intervention days compared to the baseline day. As hypothesised, participants also reported feeling significantly more vital, energetic and alert on the intervention days compared to the baseline day. The present results from four independent office environments demonstrate that lighting systems delivering a CS $\geq$ 0.3 can reduce sleepiness and increase vitality and alertness in office workers.

1. Introduction

The circadian system keeps people synchronised with the 24-hour day by regulating a wide range of physiological and behavioural systems, from digestion, to the release of hormones, to controlling core body temperature, to when a person feels alert or sleepy. Light–dark patterns on the retina are the major synchroniser of the circadian system's master clock to a person's local position on Earth. If left in darkness, the master clock will free-run with a period that is slightly greater than 24 hours. As a result, the plethora of physiological and behavioural systems that help to ensure well-being, if not survival, become asynchronous with each other and with the environmental light–dark pattern.

The retinal mechanisms underlying circadian phototransduction, which is how the retina converts light signals into electrical signals for the master clock, have recently been elucidated. How these retinal mechanisms affect the master clock in the suprachiasmatic nuclei (SCN), as well as subsequent

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physiology, is still being studied. The retinal photoreceptors, the neural pathway from the retina to the SCN as well as the pathway from the SCN, through the superior cervical ganglion in the spinal cord, to the pineal gland that synthesises the hormone melatonin at night, however, have all been described. We also know that suppression of melatonin synthesis is maximally sensitive to short-wavelength light, with a peak at about 460 nm. Rea *et al.*[1,2] proposed a mathematical model of human circadian phototransduction based upon the published spectral sensitivity data. The model is also based on fundamental knowledge of retinal neurophysiology and neuroanatomy, including the operating characteristics of circadian phototransduction, from response threshold to saturation.[3]

According to the model, the spectral irradiance at the cornea is first converted into circadian light (CL_A), reflecting the spectral sensitivity of the circadian system, and then, second, transformed into circadian stimulus (CS), reflecting the absolute sensitivity of the circadian system (amount of light, from threshold to saturation, needed to suppress melatonin). Thus, CS is a measure of the *effectiveness* of the retinal light stimulus for the human circadian system, as measured by acute melatonin suppression, from threshold ($CS = 0.1$) to saturation ($CS = 0.7$). It is important to note that, strictly speaking, CL_A and CS characterise the spectral and absolute sensitivities of light-induced nocturnal melatonin suppression via the SCN. It is assumed, however, that CL_A and CS characterise the spectral and absolute sensitivities of the entire human circadian system because the SCN is the central link to a wide variety of daily regulatory functions, like hormone production and sleep. More specifically, for the purpose of the present study, it was assumed that the spectral and absolute sensitivities of nocturnal melatonin suppression are similar to those controlling light-induced changes of circadian timing. In other words, the light stimulus that evokes acute melatonin suppression has similar characteristics to the light stimulus needed to promote entrainment. While both parsimonious and logical, this assumption has not been empirically validated.

Light can also elicit an acute, alerting effect on humans, similar to a 'cup of coffee,' at any time of day or night. For example, light has also been shown to decrease subjective sleepiness and to increase brain activity and certain types of performance, both night and day.[4–8] We know the phototransduction mechanisms responsible for nocturnal melatonin suppression are not identical to those responsible for these acute effects because saturated blue (460 nm, close to the spectral sensitivity peak for nocturnal melatonin suppression), saturated red (630 nm) and polychromatic white (4000 K, 4500 K and 5000 K) light can elicit an alerting effect at any time of day and night.[9–11] Little is known, however, about the spectral and absolute sensitivities of the mechanisms responsible for these acute effects.

Notwithstanding the fact that during the day, melatonin is not synthesised by the pineal gland and short-wavelength light will have no measureable effect on daytime melatonin concentrations, in a previous field study we investigated the relationship between morning and daytime circadian-effective light (measured in terms of CS) and office workers' sleep and mood.[4] The results showed that office workers who received high circadian-effective light levels ($CS \geq 0.3$) in the morning fell asleep faster at night (especially in the winter), experienced better sleep quality and had overall lower levels of depression compared to those who received low levels ($CS \leq 0.15$) in the morning. High levels of circadian-effective light during the entire work day were also associated with reduced depression and increased sleep quality. These findings are consistent with the inference that 'high' levels of circadian-effective light during the day promote circadian entrainment. Because light also has an acute alerting effect, we hypothesised that exposure to 'high' levels of circadian-effective light during the day might also increase alertness and vitality in office workers. What constitutes 'high' light levels for the present study was therefore operationally defined as a $CS \geq 0.3$ at the plane of the seated participant's cornea.

2. Method

2.1. Field study sites and participants

Volunteers from the U.S. Department of Veterans Affairs (VA) Medical Center in White River Junction, Vermont, and the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center in McLean, Virginia, participated in the study during both summer (July to August 2016) and fall (October to November 2016). In addition, volunteers from two U.S. embassies, one in Reykjavík, Iceland, and the other in Riga, Latvia, participated in the study during the winter of 2016 only (December 2016).

Prior to the lighting intervention at all four sites, baseline photometric analyses were conducted in participants' offices and workspaces to ensure that the lighting interventions used in the study would be of sufficient output to achieve the criterion value of $CS \geq 0.3$ (see Section 2.2). At the VA site, all participants worked in private offices and most had little or no access to daylight. Participants at the FHWA site worked in both open-plan and private offices, and some workspaces had access to daylight while others were entirely windowless. Several participants at the FHWA site had access to daylight and were already receiving a morning $CS \geq 0.3$. These participants took part in the study but did not receive any additional lighting intervention through supplemental electric lighting.

Lighting intervention data were collected in the summer (July to August 2016) and fall (October to November 2016). A total of 11 participants (eight females) from the VA site (mean age 48.3 years) and 25 participants (nine females) from the FHWA site (mean age 53.2 years) agreed to take part in the study in the summer. Of those, eight participants (seven females) from the VA site (mean age 47 years) and 18 participants (seven females) from the FHWA site (mean age 53.2 years) agreed to repeat the study in the fall (Table 1).

Thirteen participants (five females) from the Riga site (mean age 41.8 years) and 19 (seven females) from the Reykjavik site (mean age 43.2 years) volunteered for the study (Table 1). While demographic data were not collected from the embassy participants, based on their surnames, it was determined

Table 1 Summary of demographic data for participants in this study, by site

Site	Mean age (yr)	Gender: Female (*n*)	Gender: Male (*n*)	Total (*n*)
White River Junction Department of Veterans Affairs (VA)				
Summer	48.3	8	3	11
Fall	47.0	7	1	8
Turner–Fairbank Highway Research Center (FHWA)				
Summer	47.0	9	16	25
Fall	53.2	7	11	18
U.S. Embassy, Riga, Latvia	41.8	5	8	13
U.S. Embassy, Reykjavik, Iceland	43.2	7	12	19
Total, all sites		43	51	94

that 10 participants were native Latvians and 15 were native Icelanders, with the remainder being U.S. nationals (about 30% and 27% by site, respectively) who were working in the respective host countries. Most participants in the U.S. embassies worked in private offices, although a few of them worked in two-person offices.

2.2. Lighting interventions

Because one goal of this study was to demonstrate that the criterion value of $CS \geq 0.3$ can be achieved in several ways, multiple light source spectra were used, and two types of luminaires (i.e. desktop and overhead) were developed or procured.

As only a limited number of workspaces (all at the FHWA site) would permit the installation of additional overhead polychromatic white lighting for the intervention, plug-in LED-based luminaires were developed by the Lighting Research Center (LRC) for mounting on desktops near computer monitors (Figure 1), either on an elevated stand above the monitors or resting on office furniture below the monitors. One luminaire type employed a polyvinyl chloride (PVC) commercial rain gutter (4 inch × 2.5 inch × 20 inch (10.2 cm × 6.4 cm × 50.8. cm)) housing

Figure 1 The desktop luminaires used in this study: the devices installed at the VA and FHWA sites (top left and right) and the lower profile devices installed at the embassy sites (bottom left and right)

fitted with either cool-white (CCT = 6000 K) or blue (λ_{max} = 470 nm) LED strips (Ebestrade, Portland, OR) that were covered by a polyethylene diffuser (McMaster-Carr, Robbinsville, NJ) and powered by a 12-V dc adapter. These luminaires, which were used at the VA and FHWA sites, were placed either on furniture below the participants' computer displays or mounted above the displays on LRC-built stands, based on user preference and/or the physical limitations of a given workspace. The placement of the lighting intervention was determined by the need to deliver light at the cornea.

The other luminaire type used at the U.S. embassies employed lower profile, multipurpose aluminum rectangular (1.44 inch × 1.44 inch × 19 inch (3.7 cm × 3.7 cm × 48.3 cm)) bar housings (Glowback ALUMV6, Bluegate Inc., Miami Gardens, FL) fitted with either cool-white (CCT = 6000 K) or blue (λ_{max} = 470 nm) LED strips (Ebestrade, Portland, OR). The blue LED luminaires employed the plastic diffusers (Outwater Plastic, Bogata, NJ) that were shipped with the housings. The cool-white luminaires employed polyethylene diffusers (McMaster-Carr, Robbinsville, NJ) to permit the greater light transmittance required for delivering the criterion value of CS ≥ 0.3 using the cool-white LEDs. Each luminaire was mounted on a telescopic shaft, desktop microphone stand (model DS7200B, On-Stage, Berlin, CT) and powered by a 12-V dc adapter connected to an extension cord and a United States to northern European Union adapter.

The relative spectral power distributions of the cool-white and blue luminaires are shown in Figure 2. Because no differences in outcomes were expected to exist between them, participants were permitted to choose either a cool-white or blue light desktop luminaire based on their preference. (Given that the cool-white luminaire had to deliver higher amounts of light to achieve the same CS as the blue luminaire, some participants expressed a preference for the latter.)

The FHWA site provided an opportunity to install additional overhead lighting above eight workspaces. Workspaces equipped with additional overhead lighting did not receive desktop luminaires. The equipment employed in this intervention is a new type of lighting infrastructure called Power over Ethernet (PoE), which uses low-voltage data cabling to provide both power and control commands to LED luminaires via Ethernet. The overhead lighting and laptop/software system to control the luminaires were loaned by the manufacturer (CREE, Inc., Durham, NC).

The overhead luminaires were 2 ft × 2 ft (61 cm × 61 cm) troffers (Figure 3) that could be set for one of a range of correlated colour temperatures (4000 K, 4500 K and 5000 K (see Figure 2)). Light levels could be dimmed by adjusting the specific occupancy sensor settings. Because participants did not have a manual switch to turn off their overhead lights when they left for the day, the integral occupancy sensors were programmed to turn off the lights 20 minutes after no motion was detected.

The lighting interventions were designed and calibrated to deliver a criterion value of CS ≥ 0.3 at participants' eye level, and researchers collected photometric data at all four sites using a spectrometer (model USB650, Ocean Optics, Dunedin, FL) and an illuminance meter (model X9-1, Gigahertz-Optik, Amesbury, MA) to ensure that the criterion CS value was being met. Photometric conditions and CS levels were measured at eye level for all participants' workspaces, first with the lighting intervention turned off and then with the lighting intervention energised as it would be on Days 2 and 3 of the study (Figure 4). In the case of participants' workspaces with access to daylight at the FHWA site, window blinds were closed for the first measurement and open for the second measurement, with the overhead lighting remaining energised for both measurements. The mean ± standard error of the

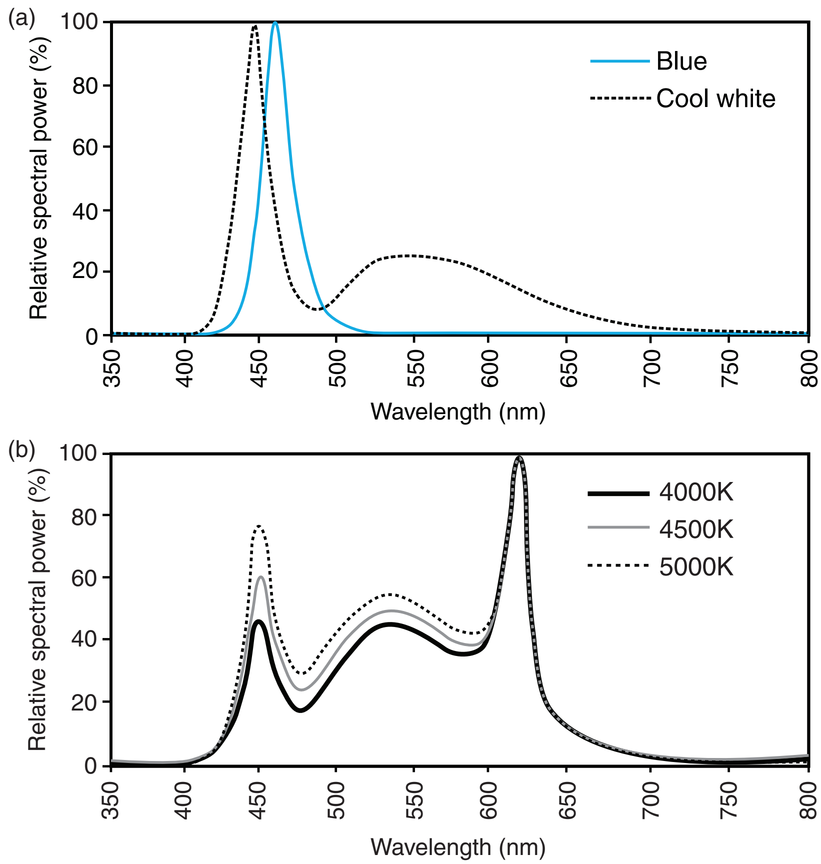

Figure 2 Relative spectral power distributions of the cool-white light and blue light desktop luminaires (top) and overhead lights (bottom) used in this study. The overhead luminaires were used at the FHWA site only

mean (SEM) photopic light levels experienced by the participants at the eye during the lighting intervention (i.e. on Days 2 and 3) were 266 ± 44 lx at the VA site, 415 ± 39 lx at the FHWA site, 410 ± 52 lx at the Riga site and 268 ± 58 lx at the Reykjavik site.

2.3. Data collection and protocol

The Daysimeter, a calibrated light-measuring device, was used to collect personal light and activity data from the participants. The Daysimeter is calibrated in terms of orthodox photopic illuminance (lx) and of circadian illuminance (CL_A), which is then converted to a CS value. Participants wore the Daysimeter during work hours so that the amount of CS they were exposed to during work could be recorded. Participants removed the Daysimeter at the end of the day and left it on their desk before departing from work. The Daysimeter has been successfully employed to obtain accurate measurements of corneal light exposures in previous studies.[12]

Participants completed several questionnaires seeking responses on sleep habits (Pittsburgh Sleep Quality Index (PSQI)[13] and Karolinska Sleepiness Scale (KSS)[14]), stress (Perceived Stress Scale (PSS-10)[15]) and subjective feelings about vitality and alertness (Subjective Vitality Scale (SVS)[16]). The PSQI

Figure 3 Examples of the 2 ft × 2 ft (61 cm x 61 cm) troffers (indicated by the arrows) used for the polychromatic white lighting intervention at the FHWA site

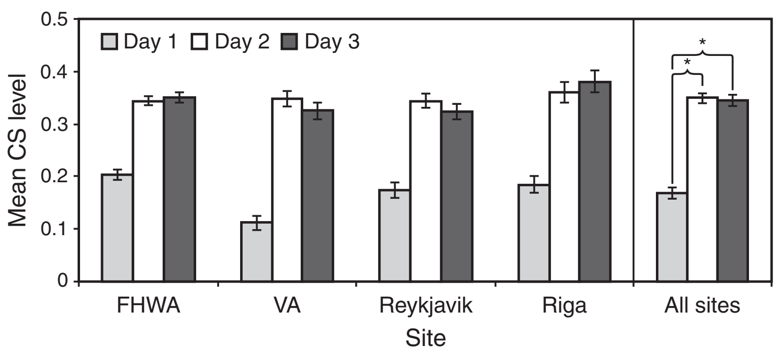

Figure 4 Mean CS values measured at the eye for each study day, by site and all sites combined. The error bars represent the standard error of the mean. The asterisks indicate statistical significance ($p < 0.05$)

and PSS questionnaires were filled out once at the start of the study. The KSS and SVS questionnaires were filled out on all three days of the study, four times per day. The KSS questionnaire is a subjective measure of sleepiness that assesses participants' present state on a nine-point scale ranging from one ('extremely alert') to nine ('very sleepy, great effort to keep awake, fighting sleep'). The SVS questionnaire assesses participants' perceptions of feeling alive, vital, energetic or energised, alert, awake and optimistic 'at the present time.' The participants' responses to seven individual statements were scored on a seven-point scale ranging from one ('not at all true') to seven ('very true'). These questionnaires were selected because they have been used to probe participants' subjective sleepiness, vitality and energy levels in previous studies.[17–20]

The study was conducted over three days; baseline data collection was performed on Day 1 and intervention data collection was performed on Days 2 and 3. The protocol is presented in Figure 5. The same Daysimeter, questionnaire and logout routines were maintained for all experimental lighting interventions on each day of the study. At the end of Day 3, the participants placed their Daysimeters and completed questionnaires into a sealed envelope, which they then submitted to the on-site point of contact for return to the research team. The protocol ran during the summer and was repeated during the fall in the FHWA and VA sites. The two U.S. embassies participated during the winter only.

On Day 1, participants with the desktop luminaire kept them turned off in order to record baseline lighting conditions. On Days 2 and 3, participants turned on their desktop luminaire upon arrival and left them on for the entire workday. Participants at the FHWA site who experienced the polychromatic white overhead luminaires were exposed to that intervention for the entire workday on Days 2 and 3 only. Because the additional overhead luminaires were centrally controlled without access to individual wall switches, participants exposed to this second intervention conducted their Day 1 baseline assessment over an established period when the additional overhead lighting was turned off. Because the Days 2 and 3 data collections were not necessarily performed immediately following the baseline day, the additional overhead lighting remained on over a period of several weeks.

The participants at the FHWA site who had access to daylight, and thus were already receiving a morning CS $\geq$ 0.3, were asked to close their window blinds on Day 1 while the existing overhead lighting remained on. Upon arrival at work on Day 2, the participants were asked to open the blinds and leave them open until the end of the protocol. The existing overhead luminaires remained energised during Days 2 and 3.

2.4. Data analyses

Studies that use the SVS questionnaire often report the results separately for each of the seven component items. However, this practice is inconsistent with the scale's intended purpose of measuring the single construct its developers termed *subjective vitality*.[16] During its initial development, the SVS was a 19-item survey that was subsequently factor analysed, producing two separate dimensions. The first and most robust factor consisted of seven items that comprise the current SVS. The seven-item scale demonstrated adequate internal consistency assessed via Chronbach's alpha ranging from 0.84 to 0.86. Subsequent research has provided psychometric support for a shorter six-item version (e.g. see Bostic *et al.*[19]). We administered the seven-item SVS measure to

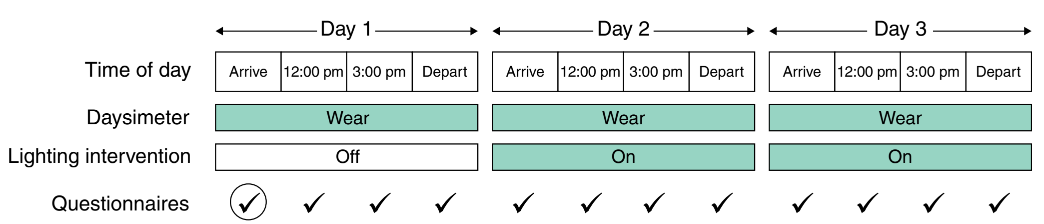

Figure 5 The three-day protocol for the study. The lighting interventions were operational on Days 2 and 3 following the baseline Day 1. All three days of the study while at work, participants wore the Daysimeter, completed both the KSS and SVS questionnaires at the four established times (indicated by check marks), and logged time away from their workspaces. Participants completed the PSQI and PSS-10 questionnaires once upon arrival at the office on Day 1 only (indicated by circle). It should be noted that window blinds were closed in the FHWA building during the baseline measurements, but open during the two intervention days

participants, but then applied principal axis factoring to examine its scale properties. The Kaiser–Meyer–Olkin measure of sampling adequacy (0.93) and Bartlett's test of sphericity ($X^2(21) = 5860.23$, $p < 0.001$) indicated the data set was suitable for factor analysis. The rotated solution using Varimax rotation confirmed a single factor (eigenvalue = 4.82) that accounted for 69% of the variance. Reliability was moderate (Chronbach's alpha = 0.70). Consistent with the findings of Bostic *et al.*,[19] eliminating SVS Statement 2 ('I don't feel very energetic') increased scale reliability substantially (Chronbach's alpha = 0.91). Based on these results, we subsequently used a composite measure comprised of the average of the six-item SVS scale in the main analyses.

2.5. Lighting intervention check

A one-way analysis of variance (ANOVA) was conducted using the Daysimeter data to determine whether the lighting intervention was implemented as planned across the three-day study period. As expected, CS values for the study days were significantly different, $F(2, 1014) = 216.64$, $p > 0.001$. *Post-hoc* tests using the Sidak procedure[21] showed significant ($p < 0.01$) differences in mean CS levels between Day 1 (0.18 (SEM = 0.006)) and Days 2 (0.34 (SEM = 0.007)) and 3 (0.34 (SEM = 0.007)). There was no significant difference between Days 2 and 3 ($p > 0.05$).

2.6. Main analyses

Separate mixed-model regression analyses were performed to examine the effects of the lighting intervention on the composite mean KSS and SVS scores, respectively. 'Study Day,' 'Time of Day' and 'Site' were entered into the model as fixed effects variables. 'Participant' was entered as a random effects variable. The CS, PSS-10 and PSQI measures were entered as covariates. As the factor 'Site' did not reach statistical significance ($p > 0.05$) in the initial analyses, mixed-model regression analyses were therefore performed on the combined data from all four sites. It is important to note that the KSS and SVS scores recorded across each day of the study appeared quite similar for all four sites, thus reinforcing the results of the regression analysis and, further, supporting the decision to draw subsequent statistical inferences from the combined data.

3. Results

3.1. Effect of intervention on the composite mean SVS scores (subjective vitality)

There was a significant main effect of Study Day, $F(2, 819.63) = 13.40$, $p < 0.001$. As shown in Figure 6, composite mean SVS scores increased from Day 1 (4.23 (SEM = 0.12)) to Day 2 (4.35 (SEM = 0.12)) to Day 3 (4.62 (SEM = 0.12)). Pairwise comparisons using the Sidak procedure showed significant differences in mean SVS scores between Days 1 and 3 ($p < 0.05$) and between Days 2 and 3 ($p < 0.05$). The difference between Days 1 and 2 was not significant ($p > 0.05$).

There was a significant main effect of Time of Day, $F(3, 802.51) = 5.34$, $p < 0.01$. Composite mean SVS scores increased between arrival (4.24 (SEM = 0.12)) and 12:00 p.m. (4.53 (SEM = 0.12)), then decreased thereafter from 3:00 p.m. (4.45 (SEM = 0.12)) through departure (4.38 (SEM = 0.12)). Pairwise comparisons using the Sidak procedure showed significant differences in mean SVS scores between arrival and 12:00 p.m. ($p < 0.05$) and between arrival and 3:00 p.m. ($p < 0.05$). No other comparisons were significant ($p > 0.05$). The Study Day × Time of Day interaction was not significant ($p > 0.05$).

3.2. Effect of intervention on KSS scores (subjective sleepiness)

There was a significant main effect of Study Day, $F(2, 837.53) = 3.14$, $p < 0.05$ (Figure 7). The composite mean KSS scores decreased

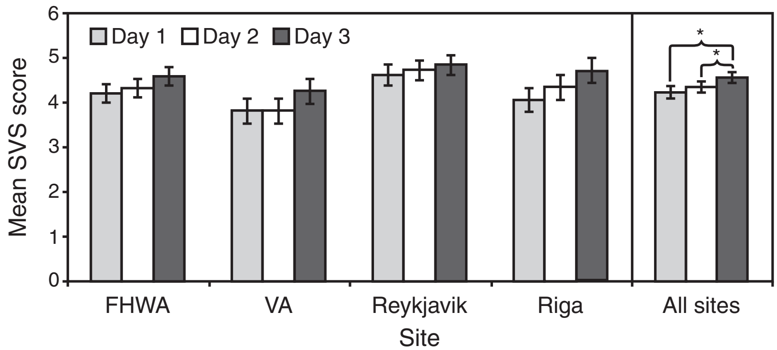

Figure 6 Mean SVS scores for each study day, by site and all sites combined. The error bars represent the standard error of the mean. The asterisks indicate statistical significance ($p < 0.05$)

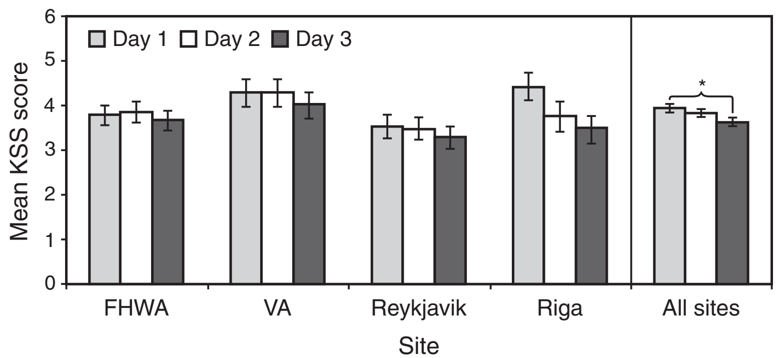

Figure 7 Mean KSS scores for each study day, by site and all sites combined. The error bars represent the standard error of the mean. The asterisk indicates marginal statistical significance ($p = 0.06$)

from Day 1 (3.94 (SEM = 0.14)) to Day 2 (3.83 (SEM = 0.14)) to Day 3 (3.63 (SEM = 0.14)). Pairwise comparisons using the Sidak procedure showed a marginally significant difference between Days 1 and 3 ($p = 0.06$). No other differences were significant ($p > 0.05$).

There was a significant main effect of Time of Day, $F(3, 805.48) = 5.70$, $p < 0.01$. Pairwise comparisons using the Sidak procedure showed significant differences between 12:00 p.m. and 3:00 p.m. ($p < 0.05$) and between 12:00 p.m. and departure ($p < 0.05$), as well as a marginally significant difference between arrival and 12:00 p.m. ($p = 0.051$). No other comparisons were significant ($p > 0.05$). In general, sleepiness decreased from arrival to 12:00 p.m. and then increased through the day until departure. The Study Day × Time of Day interaction was not significant, $F(6, 796.38) = 0.50$, $p > 0.05$.

4. Discussion and conclusions

The present study demonstrated that CS ≥ 0.3 during daytime hours is associated with an acute alerting effect on office workers during two working days. What is particularly remarkable is that four independent office buildings all showed the same trends; during the two days of the lighting intervention, workers' self-reports of sleepiness during working hours decreased while those of alertness, vitality and energy increased.

As we hypothesised, self-reported sleepiness (KSS) scores were reduced on Days 2 and 3 (i.e. during the intervention) compared to baseline Day 1. The KSS scores throughout the workday displayed a U-shaped pattern, with higher subjective sleepiness scores upon arrival and at the end of the day and lower scores (indicating less sleepiness) during midday. This pattern changed during the intervention. The KSS scores at each time of the day were divergent on Day 1, but by Day 3 the scores converged around their lower limit at all four time points, suggesting that subjective sleepiness remained lower throughout the entire workday. This effect was more pronounced on Day 3 than on Day 2, suggesting a cumulative effect of the lighting intervention on subjective sleepiness.

Also as hypothesised, the participants reported feeling significantly more vital, more energetic and more alert on Days 2 and 3 (i.e. during the intervention) compared to baseline Day 1. Self-reports of vitality increased over the course of the day, indicating greater feelings of vitality at departure than upon arrival. Reported energy levels were greater in the middle of the day than they were upon arrival or at departure on the first day, but this difference was less pronounced during intervention days, especially during Day 3. The SVS scores during the intervention days remained high over the course of the entire day.

The use of different lighting modes to deliver the intervention in different buildings did not produce significantly different results. *Post hoc* analyses showed no significant differences in participants' responses that were based on the type of luminaire used during the study. New LED technologies that are now commercially available made it possible for us to deliver our criterion circadian-effective light in both private offices and cubicles, with and without access to daylight. Additionally, tuning the lighting intervention's spectrum to decrease the amount of electric power needed to deliver the desired CS level at the eye may be the most efficient way to create both effective and comfortable working environments.

As stated in the Introduction, although the spectral and absolute sensitivities of acute alertness have not been elucidated, previous studies clearly demonstrated that both short-wavelength and long-wavelength light will elicit an acute alerting effect on people during the day and at night, and that nocturnal melatonin need not be suppressed to have an acute alerting effect on people. Thus, while light exposure at the cornea expressed in terms of CS is certainly meaningful for specifying light stimuli for the human circadian system, it is probably not the most accurate metric for characterising the alerting effects of light because red light has been shown to increase alertness, performance and brain activity without suppressing melatonin at night.[11,22]

It is important to note that participants were not asked to report on their caffeine intake during the day. As it is known that caffeine affects sleep pressure by blocking adenosine receptors,[23] caffeine intake therefore could have influenced participants' subjective feeling of alertness, sleepiness and vitality. It seems unlikely, however, that caffeine consumption would have differed across days at all four sites.

Finally, it is worth repeating that the circadian-effective lighting intervention ($CS \geq 0.3$) was delivered for only two days, without controlling light exposures outside the work environment. The history of exposures to the overhead lighting at the FHWA site, moreover, was not consistent between participants. During the summer, for example, two participants experienced the overhead lighting intervention prior to data collection for twleve days, one participant experienced it for thirteen days, two participants experienced it for two days, and one participant experienced it for eight days. In the fall data collection, three participants experienced the overhead lighting intervention two days prior to data collection and two participants experienced it for twelve days. The researchers did not observe any significant difference in questionnaire responses between the participants who experienced the intervention for two days (the minimum) and those who experienced it for thirteen days (the maximum) prior to data collection. Further studies should investigate the impacts of history and duration of lighting interventions on daytime sleepiness and energy levels.

Evening light exposures can be just as important as morning light exposures when it comes to entrainment of the circadian system, so we cannot conclude that the effects were based simply on high daytime CS exposure. It is, however, logical to infer from the results of the present study and those from a wide range of laboratory studies, that 'high' light levels at the cornea during the day will (a) better align circadian rhythms to a day-active and night-sleeping pattern and (b) increase alertness during working hours.

These promising empirical results from the field, backed up by more basic research, justify further investigations of the impact of retinal light exposure on the neurophysiology of the brain and, perhaps more importantly, a reexamination of current lighting standards based only upon the impact of office illumination on visibility and comfort.

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