Influence of Daytime Short-Wavelength Dominant Electric Light Exposure on Human Alertness And Higher Cognitive Functions: A CIE S026-Based Pilot Study.

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# Abstract

We tested the effect of daytime short-wavelength dominant light exposure on alertness and higher cognitive functions among university students using spectrally tunable lights. Participants (n = 24; mean age ± SD = 23.96 ± 2.42 years; 8 F) were randomized to a two-hour daytime exposure to one of three light conditions with photopic illuminance maintained at 285 ± 2 lx; measured at horizontal plane at 2’6” and 170 ± 10 lx measured at eye level vertical plane at 4” with three different melanopic daylight efficacy ratio (MDER; High: 0.91 MDER, 164 MEDI, 6793 K; Neutral: 0.63 MDER, 108 MEDI, 4248K, Low: 0.45 MDER, 72 MEDI, 2592 CCT). Along with subjective measures of alertness, a robust cognitive battery including auditory psychomotor vigilance task (aPVT), N-back task, digit-span, and tower of London were administered to measure attention and higher cognitive functions. A significant main effect of light exposure (p =0.01, η2=0.35.) on subjective alertness was observed where participants reported higher subjective alertness under high MDER light settings in comparison to neutral (p =.02) and low (p=.04) MEDI light settings. No main effect of light exposure was observed in the performance of aPVT, N-back task (accuracy, reaction time), Tower of London (efficiency, planning time, execution time), and digit span task (forward, backward and sequential). These results demonstrate that exposure to high-MDER (short wavelength-enriched) light improves subjective alertness. However, further investigation is required to understand the possible influence of short-wavelength dominant light on higher cognitive functions.

*Keywords:* light exposure, non-visual effects of light, alertness, cognition.

# Introduction

Besides its role in vision, light also influences several physiological and psychological processes - known as ‘intrinsically photosensitive retinal ganglion cell (ipRGCs) influenced light (IIL) responses’ (CIE, 2018a). IIL responses can be categorized as circadian, neuroendocrine and neurobehavioral responses (IES, 2018). The IIL responses are highly dependent on the spectrum (Houser et al., 2020). Figure 1 depicts the complex dependency of IIL responses on different spectral properties.

Graphical user interface, application

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Figure 1. Light can affect our psychological functioning. These effects are sensitive to different light properties. Adapted from Borisuit (2013)

It is evident from the literature that electric light can influence different aspect of physiological and psychological aspects including alertness, higher cognitive functions, mood, sleep-wake cycle. Studies that report beneficial influences of short-wavelength dominant light exposure or high-illuminance white light exposure are mostly unrealistic in terms of light source characteristics. The use of monochromatic light, narrowband filter or higher CCT lights are not common and suitable in real settings. Also, for daily usage, high-intensity lights, which are reported to enhance alertness and cognition (≥1000 lx), are not commonly suggested by the guidelines (DOSH, 2018) and are also not very cost-effective. To strengthen the effort of the Malaysian government to increase ecological safety and become a global green technology hub (Li, 2013), our current study tries to provide a better light solution that will reward individuals, especially students in terms of enhanced alertness and higher cognitive performance in a cost-effective and safe manner.

# Method

**Participants**

Due to the obstacles we faced for the limited campus access, we ended up collecting data from twenty-four Monash university students. All our participants were physically and psychologically healthy; they passed the Ishihara Colour Blindness test administered in our lab. A RM 40 voucher was given to each participant for their participation. The ethics committee of Monash University approved all the study materials and procedures, and the participants signed informed consent before the commencement of the study.

**Design**

We employed a between-group design with three different MDERs to investigate the differential impact of light on alertness & higher cognitive functions. Participants were randomly assigned to the three light conditions. The independent variable was the modulation melanopic Equivalent Daylight Illuminance (MEDI). The dependent variable would be alertness, and higher cognitive functions.

Our neutral setting (0.7) reflected the commercially available fluorescent light settings as closely as possible. This enabled us to compare the impacts of Fluorescent light and LED lights on student’s alertness and performance Our high light setting (1.0) was tailored to provide high energy to the shorter wavelength region of the light spectrum. The low setting (0.5) was considered as a controlled setting.

**Materials**

***Karolinska Sleepiness Scale.*** We used Karolinska Sleepiness Scale (Åkerstedt & Gillberg, 1990) to measure subjective sleepiness. Participants rated their sleepiness hourly using the KSS, a 10-point scale from 1- "very alert" to 10 - "Extremely sleepy, can't keep wake". Participants also rated their alertness in a "sleepy-alert" VAS ranging from "0-10".

***Positive and Negative Affect Schedule.*** The positive and negative affect schedule (PANAS) (Watson, Clark, & Tellegen, 1988)was used to measure positive and negative affect. PANAS is comprised of two 10-item mood scales measuring positive affect (PA) and negative affect (NA). In this study participants rate their positive and negative affect based on the last one month retrospectively using a five-point Likert type response scale (1 = very slightly/not at all; 2 = a little; 3 = moderately; 4 = quite a bit; 5 = extremely).

***Pittsburgh Sleep Quality Index.*** We used the Pittsburgh Sleep Quality Index (PSQI) (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) to measure the sleep quality of the participants. PSQI measures seven domains of sleep to differentiate “poor” from “good” sleep. Participants responded to the PSQI using a Likert type responses option ranging from zero the three, whereby 3 reflects the negative extreme on the Likert Scale. A sum of scores equal to or greater than five indicates poor sleep quality. Though Buysse et al. (1989) reported a one-factor structure of the scale, it is evidenced that the factor structure of PSQI varies from one factor to three factors (Manzar et al., 2018). Dunleavy et al. (2019) in their study recommended using a two-factor model: perceived sleep quality (PSQ) and sleep efficiency (SE) while measuring the sleep quality among Singapore citizens. In this study, we followed their recommended structure.

***Morningness-Eveningness Questionnaire.*** Chronotype was measured using the Morningness-Eveningness questionnaire (MEQ) (Horne & Östberg, 1976). MEQ consists of 19 questions and the scores range from 16 to 86. A higher score indicates more morning propensity. Caci, Deschaux, Adan, and Natale (2008) reported a four-factor structure of MEQ: peak time (PT), morning affect (MA), retiring (RT) and rising (RI) in s student sample.

***N-back.*** One-back and three-back tests were used to measure working memory and executive functions of the participants (Jonathan et al., 1997). During the task, auditory one-digit numbers were presented successively. The Participants were instructed to judge whether the current digit matches the digit presented one digit previously (one-back) or two-digit previously (three-back) and react quickly and accurately as possible by pressing the assigned keys (labelled "Yes" and "No") on the keyboard. Each digit was presented for 500mn with an inter-stimulus interval of 1500ms.

***Psychomotor Vigilance Test.*** Ten minutes of auditory psychomotor vigilance test (PVT 10A) was used as an objective measure of alertness. During the PVT-10A, an auditory signal was presented at a random interval (1-9s), and the participants were asked to press a button as soon as possible after hearing the sound.

***Tower of London.*** The Tower of London test (Shallice, 1982) was used to measure executive functioning. Participants were presented with boards with three poles attached on top of it. Participants were then asked to manipulate the board to achieve the arrangement presented in the goal state, with as few moves and as quickly as possible performance on this task was used to derive executive function, specifically problem-solving skills and mental planning.

***Digit Span Task.*** The Digit Span Task is a simple behavioural measure of working memory capacity. This was verbally administered. This test has three sections: Forward Digit Span, Backward Digit Span, Sequential Digit Span. On each trial, participants were read aloud with a series of digits one at a time. In the forward-span variant, participants attempted to recall the digits in the order they were presented. In the backward-span variant, participants attempted to recall the digits in the reverse order. In the sequential-span variant, at the end of each list participants attempted to recall the digits in sequential order. In each variation, there were eight items, each with two trials per item. The number of digits presented increased by one for the next item. The task concluded after participants make errors for two trials in a row for a given digit span.

Diagram

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Figure 2: Cognitive tasks used in our study 2.

**Protocol**

Each participant spent approximately two hours in our lab in a time cue free environment. They were allowed thirty minutes to attune to the light condition. During that time, they answered a series of a questionnaire regarding their demographic information and medication history. After that aPVT, N-back test, digit span, and Tower of London test were administered. Subjective measures of sleepiness & alertness were recorded both at the beginning and the end of the test**.**

Diagram

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Figure 3: Protocol of study 2.

# Results

**Sleepiness assessment**

A one-way ANOVA was conducted to see whether subjective alertness differed significantly under the three light conditions. The outliners were adjusted, and the data was normally distributed except for (high light settings) as assessed by Shapiro-Wilk test (p > .05). Homogeneity of variances was held, as assessed by Levene's Test of Homogeneity of Variance (p >.05). The results showed a significant main effect of light on subjective alertness, (F(2,21) =5.58, p = .01, η2 = 0.35). Subjective alertness was increased under high MEDI light settings (1.1± 1.1) than under neutral MEDI (-0.86±1.6) and low MEDI (-.71±1.5) light settings. Bonferroni post hoc analysis revealed a statistically significant increase in alertness under high light setting compared to neutral (p = .02) and low light settings (p=.04)

Chart, box and whisker chart

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*Figure 4*. Main effect of light settings on subjective alertness.

**Auditory Psychomotor Vigilance Task**

A one-way ANOVA was conducted to see whether reaction time differed significantly under the three light conditions. The outliners were adjusted and the data was normally distributed except for (high light settings) as assessed by Shapiro-Wilk test (p > .05). Homogeneity of variances was held, as assessed by Levene's Test of Homogeneity of Variance (p >.05). The results showed no significant main effect of light on subjective alertness, (F(2,21) =1.28, p = .29, η2 = 0.11).

Chart, box and whisker chart

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*Figure 5.* Main effect of light on reaction time

**Digit Span Task**

A one-way ANOVA was conducted to see whether task performance differed significantly under the three light conditions. The outliners were adjusted and the data was normally distributed except for high light settings in digit span sequence task as assessed by Shapiro-Wilk test (p > .05). Homogeneity of variances was held, as assessed by Levene's Test of Homogeneity of Variance (p >.05). The results showed no significant main effect of light on forward digit span (F(2,21) =1.74, p = .20, η2 = 0.14), digit span backward (F(2,21) =.0693, p = 0.51, η2 = .06), digit span sequence (F(2,21) =0.23, p = 0.80, η2 = .02)

Chart, box and whisker chart

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*Figure 6.* Main effect of Light on Digit Span

**One Back & Three back Task**

A one-way ANOVA was conducted to see whether reaction time and accuracy differed significantly under the three light conditions in one back and three back tasks. There was no outliner and the data was normally distributed except for neutral light settings in one back reaction task as assessed by Shapiro-Wilk test (p > .05). Homogeneity of variances was held, as assessed by Levene's Test of Homogeneity of Variance (p >.05). The results showed no significant main effect of light on one back task accuracy (F(2,21) =1.12, p = .34, η2 = 0.10), one back reaction time (F(2,21) =.0693, p = 0.51, η2 = .06) and three back accuracy (F(2,21) =.55, p = .59, η2 = 0.05) . However, the main effect of light was approaching to statistics significance for the three back reaction time (F(2,21) =3.53, p = 0.05, η2 = .25).

Diagram

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*Figure 7.* Main effect of Light on Reaction time and accuracy in One back and Three back Tasks

**Tower of London Task**

A one-way ANOVA was conducted to see whether performance in tower of London differed significantly under the three light conditions. There was no outliners and the data was normally distributed except for low light settings as assessed by Shapiro-Wilk test (p > .05). Homogeneity of variances was held, as assessed by Levene's Test of Homogeneity of Variance (p >.05). The results showed no significant main effect of light on efficacy (F(2,21) =.041, p = .96, η2 = 0.004), planning time (F(2,21) =.35 p = 0.71, η2 = .03), execution time (F(2,21) =0.50, p = 0.61, η2 = .004) and total time (F(2,21) =0.60, p = 0.56, η2 = .05)

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# Discussion

Our results indicate a significant effect of short-wavelength dominant light exposure on subjective alertness. Mean reaction time in auditory based psychomotor vigilance have remained unaffected. Similar results were reported in previous research where visual psychomotor vigilance was found more sensitive to light exposure than an auditory based psychomotor vigilance test (Burattini et al., 2019).

Participants under three light conditions did not differ significantly in terms of their performance in the digit span task, N-Back task, and Tower of London task. This result is in contrast with the findings of the research where a forty minutes daytime light exposure yielded enhanced performance in terms of accuracy and reaction time in auditory based N-Back task (Daneault et al., 2018).

This study was not subjected to strict exclusion and inclusion criteria, thus allowing a high interindividual variability, including different homeostatic sleep drives, a different circadian cycle, and different sleep habits. Additionally, photopic lux remained the most same across the three light settings and maybe not sufficient for improving higher cognitive functions (Huiberts, Smolders, & de Kort, 2016). Further studies employing both short-wavelength dominant spectrum with higher illuminances are required to understand theses fully.

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**Tables**

**Table 1**

Description of the Participants

| Variable | Overall, N = 241 | Female, N = 81 | Male, N = 161 |
| --- | --- | --- | --- |
| Age | 23.96(2.42) | 23.88(2.64) | 24(2.39) |
| Time of Sleeping | 6.7 (5.0) | 7.9 (5.1) | 6.2 (5.0) |
| Time of Awaking | 8.92 (1.39) | 8.25 (0.93) | 9.25 (1.48) |
| Hours of Sleeping | 7.27(1.22) | 6.94(.78) | 7.44(1.38) |
| Sleep Quality |  |  |  |
| Raw PSQI | 5.29(1.97) | 5.25(1.39) | 1.56(.51) |
| Good | 9 (38%) | 2 (25%) | 7 (44%) |
| Poor | 15 (62%) | 6 (75%) | 9 (56%) |
| Chronotype |  |  |  |
| Raw Score | 46.17(9.10) | 46.38(9.05) | 46.06(9.42) |
| Definite Evening | 1 (4.2%) | 0 (0%) | 1 (6.2%) |
| Intermediate | 17 (71%) | 6 (75%) | 11 (69%) |
| Moderate Evening | 5 (21%) | 2 (25%) | 3 (19%) |
| Moderate Morning | 1 (4.2%) | 0 (0%) | 1 (6.2%) |
| 1n (%); Mean (SD) | | | |

**Table 2**

Light properties of pilot Study

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Setting | n | MDER | Measured CCT (K) | Melanopic lux | Photopic Lux |
| High | 10 | .91 | 6500 | 164 | 180 |
| Neutral | 7 | .63 | 3943 | 108 | 172 |
| Low | 7 | 0.45 | 2661 | 72 | 160 |

\*These are measured at eye level vertical plane at 4”, and the brightest point in the room with the CL-500 Spectrophotometer.

**Table 3**

Analysis of Variance Results for The Subjective Sleepiness

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | n | Mean | Standard Deviation | Standard Error | F | p | η2 |
| High | 10 | 1.1 | 1.1 | .43 | 5.58 | .01 | .35 |
| Neutral | 7 | -.86 | 1.6 | .51 |  |  |  |
| Low | 7 | -.71 | 1.5 | .51 |  |  |  |

**Table 4**

*Analysis of Variance (ANOVA) Test Results for of the aPVT Test*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| PVT | n | Mean | Standard Deviation | Standard Error | F | p | η2 |
| Reaction Time |  |  |  |  |  |  |  |
| High | 10 | .42 | .25 | .06 | 1.28 | .29 | .11 |
| Neutral | 7 | .32 | .17 | .07 |  |  |  |
| Low | 7 | .27 | .15 | .07 |  |  |  |

**Table 5**

*Analysis of Variance (ANOVA) Test Results of The Digit Span*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | n | Mean | Standard Deviation | Standard Error | F | p | η2 |
| Digit Span Forward |  |  |  |  | 1.74 | .201 | .14 |
| High | 10 | 11.20 | .034 | .82 |  |  |  |
| Neutral | 7 | 11.43 | 2.6 | .98 |  |  |  |
| Low | 7 | 9.14 | 1.57 | .98 |  |  |  |
| Digit Span Backward |  |  |  |  |  |  |  |
| High | 10 | 8.50 | 2.22 | .66 | 0.69 | 0.51 | .06 |
| Neutral | 7 | 9.71 | 2.7 | .79 |  |  |  |
| Low | 7 | 9.00 | .08 | .78 |  |  |  |
| Digit Span Sequential |  |  |  |  |  |  |  |
| High | 10 | 9.90 | 2.47 | 0.71 | 0.23 | .80 | .02 |
| Neutral | 7 | 9.57 | 2.14 | 0.86 |  |  |  |
| Low | 7 | 9.14 | 2.03 | 0.86 |  |  |  |

**Table 6**

*Analysis of Variance (ANOVA) Test Results of The One-Back and Three Test*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | n | Mean | Standard Deviation | Standard Error | F | p | η2 |
| One back |  | |  |  |  |  |  |  |
| Reaction time |  | |  |  |  |  |  |  |
| High | 10 | | .79 | .11 | .04 | .80 | .46 | .07 |
| Neutral | 7 | | .85 | .13 | .05 |  |  |  |
| Low | 7 | | .77 | .17 | .05 |  |  |  |
| Accuracy |  | |  |  |  |  |  |  |
| High | 10 | | .95 | .03 | .01 | 1.12 | .34 | .10 |
| Neutral | 7 | | .92 | .04 | .01 |  |  |  |
| Low | 7 | | .94 | .02 | .01 |  |  |  |
| Three back |  | |  |  |  |  |  |  |
| Reaction time |  | |  |  |  |  |  |  |
| High | 10 | | 1.3 | .16 | .06 |  |  |  |
| Neutral | 7 | | 1.2 | .12 | .07 | 3.53 | .05 | .32 |
| Low | 7 | | 1.0 | .23 | .07 |  |  |  |
| Accuracy |  | |  |  |  |  |  |  |
| High | 10 | | .73 | .15 | .05 | .55 | .59 | .05 |
| Neutral | 7 | | .79 | .12 | .06 |  |  |  |
| Low | 7 | | .70 | .19 | .06 |  |  |  |

**Table 7**

Analysis of Variance (ANOVA) Test Results of the Tower of London

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | n | Mean | Standard Deviation | Standard Error | F | p | η2 |
| Efficiency |  |  |  |  |  |  |  |
| High | 10 | 1.9 | .90 | .290 | .041 | .96 | .004 |
| Neutral | 7 | 1.90 | .70 | 1.180 |  |  |  |
| Low | 7 | 2.04 | 1.10 | 1.321 |  |  |  |
| Planning Time |  |  |  |  |  |  |  |
| High | 10 | 9.70 | 8.08 | 2.52 | .346 | .712 | .03 |
| Neutral | 7 | 12.42 | 8.08 | 3.01 |  |  |  |
| Low | 7 | 9.17 | 7.67 | 3.01 |  |  |  |
| Execution Time |  |  |  |  |  |  |  |
| High | 10 | 22.87 | 7.38 | 2.90 | .500 | .61 | .04 |
| Neutral | 7 | 27.37 | 8.61 | 3.46 |  |  |  |
| Low | 7 | 24.42 | 11.74 | 3.46 |  |  |  |
| Total Time |  |  |  |  |  |  |  |
| High | 10 | 32.40 | 9.95 | 4.41 | .60 | .56 | .05 |
| Neutral | 7 | 39.64 | 14.91 | 5.27 |  |  |  |
| Low | 7 | 33.48 | 17.63 | 5.27 |  |  |  |