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 XXX lx; measured at horizontal plane at XX and XX lx measured at eye level vertical plane at XX with three different melanopic daylight efficacy ratio (MDER; High: XX MDER, XX MEDI, XX K; Neutral: XX MDER, XX MEDI, XX, Low: XX MDER, XX MEDI, XX 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.

The title

# Methods

## Participants

Twenty-four healthy university students age ranging between 20-29 (mean age ± SD: 23.96 ± 2.42)- 16 females (Mean age ± SD = 23.88±2.64) and 8 males (Mean age ± SD = 24.00±2.39) were studied in the Intelligent Lighting Lab at Monash University Malaysia. The study obtained ethics clearance from the Monash University Human Research Ethics Committee (Project ID: 14786), and participants provided written informed consent prior to the study. All participants reported to be free from medical and psychological conditions and had no color blindness (tested by Ishihara Blindness Test; Clark, 1924). Most of them were poor sleepers (62%) and had intermediate chronotypes (71%).

Table 1:

| **Variable** | **Overall1**, N = 24 | **Low1**, N = 7 | **Neutral1**, N = 7 | **High1**, N = 10 |
| --- | --- | --- | --- | --- |
| Age | 23.96 (2.42) | 25.00 (2.52) | 23.29 (2.87) | 23.70 (2.00) |
| **Gender** |  |  |  |  |
| Female | 8 (33%) | 1 (14%) | 4 (57%) | 3 (30%) |
| Male | 16 (67%) | 6 (86%) | 3 (43%) | 7 (70%) |
| **Marital Status** |  |  |  |  |
| Single | 24 (100%) | 7 (100%) | 7 (100%) | 10 (100%) |
| **Education** |  |  |  |  |
| Bachelor’s Degree | 22 (92%) | 7 (100%) | 5 (71%) | 10 (100%) |
| Master’s Degree | 2 (8.3%) | 0 (0%) | 2 (29%) | 0 (0%) |
| **Sleep Quality** |  |  |  |  |
| Good | 9 (38%) | 3 (43%) | 3 (43%) | 3 (30%) |
| Poor | 15 (62%) | 4 (57%) | 4 (57%) | 7 (70%) |
| **Chronotype** |  |  |  |  |
| Definite Evening | 1 (4.2%) | 0 (0%) | 0 (0%) | 1 (10%) |
| Intermediate | 17 (71%) | 6 (86%) | 5 (71%) | 6 (60%) |
| Moderate Evening | 5 (21%) | 1 (14%) | 2 (29%) | 2 (20%) |
| Moderate Morning | 1 (4.2%) | 0 (0%) | 0 (0%) | 1 (10%) |

## 1Mean (SD); n (%)

## Light Exposure Conditions

The experimental site was at Intelligent Light Lab, Monash University Malaysia (length x width x height; xx m by xx m by xx m). The lab was furnished with one rectangular working desk with three chairs. The walls of the lab were covered with grey curtains and all glass windows were covered by blackout blinds. The room temperature was set to 25 C. The three light conditions were generated using 12 Phillips tuneable LED ceiling-mounted luminaries. Figure 1 (A-B) depicts the luminaire arrangement of the lab. We measured the light sources at the horizontal plane at desk level (80 cm) and the vertical plane at eye level of the participants seated at the desk (122 cm). Figure 1-C depicts the spectral composition of the three light conditions.

A picture containing graphical user interface

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Table 2 presents α-opic melanopic equivalent daylight illuminances (Melanopic EDI), and melanopic daylight efficacy ratio (MDER) values both at the desk (80 cm) and eye level (120 cm) for the three light conditions: (a) high MDER light settings (HM): 0.85 MDER, 210.93 MEDI, 6381 K; (b) neutral MDER light settings (NM): 0.6 MDER, 156.09 MEDI, 3875 K; and (c) low MDER light settings (LM): 0.43 MDER, 90.57 MEDI, 2648 K. The photopic lx of three light settings was kept at ~250 lx in the horizontal plane (mean=238.12; SD=±13.11) and ~230 lx in the vertical plane (mean=238.12; SD=±13.11). Each experimental session started with a 30-minute adaption period, during which the MDER was 0.60 with 250 photopic lx in the horizontal plane (79.23 μW/cm) and 139 photopic lx (42.79 μW/cm) in the vertical plane. The α-opic values and MDER values are obtained using Loux software (Spitschan et al., 2021) and CIE S 026:2018 toolbox (Schlangen, 2018) following the CIE S 026 guidelines (CIE, 2018).

**Table 2. α-opic EDI and MDER values of the three light conditions.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Horizontal plane (measured at desk level: .80m)** | | | | | | | | | |
| **Light Condition** | **Photopic lx** | **Irradiance (μW/cm2)** | **α- opic Equivalent Daylight (D65) Illuminance (lx)** | | | | | **MDER** | **CCT (K)** |
| **S cone** | **Melanopsin** | **Rod** | **M Cone** | **L Cone** |
| High | 247.17 | 81.16 | 242.09 | 210.93 | 221.15 | 239.49 | 243.22 | 0.85 | 6381 |
| Neutral | 259.82 | 79.23 | 137.75 | 156.09 | 174.23 | 226.870257 | 259.43 | 0.60 | 3875 |
| Low | 207.38 | 63.48 | 50.85 | 90.57 | 108.8808562 | 161.9572833 | 211.8043125 | 0.43 | 2648 |
| **Vertical plane (measured at Eye level: 1.2m)** | | | | | | | | | |
| **Light Condition** | **Photopic lx** | **Irradiance (μW/cm2)** | **α- opic Equivalent Daylight (D65) Illuminance (lx)** | | | | | **MDER** | **CCT (K)** |
| **S cone** | **Melanopsin** | **Rod** | **M Cone** | **L Cone** |
| High | 131.83 | 43.37 | 125.21 | 110.723337 | 116.40 | 127.00 | 129.83 | 0.84 | 6164 |
| Neutral | 139.53 | 42.73 | 71.68 | 82.62 | 92.47 | 121.15 | 139.49 | 0.60 | 3788 |
| Low | 113.98 | 35.22 | 27.23 | 49.20 | 59.26 | 88.52 | 139.49 | 0.43 | 2606 |

## 

## Study Protocol

Participants were asked not to ingest any caffeine and drink alcohol on the experiment day. Figure 1-D depicts the experimental protocol followed in this study. Each participant spent approximately two hours in our lab in a time cue free environment (all doors and windows covered with blinds, no watches, internet, mobile, TV, newspaper and radio). Each session started with an adaption period of 30 minutes, where participants participated in a practice block to familiarize themselves with the cognitive tests. At the end of the adaption block, participants were randomly exposed to one of the three light conditions. Throughout the two-hour protocol participants remained seated at their desks. Exercising and napping were not allowed. Participants took part in a series of cognitive tests in the following order: aPVT, N-back test, digit span, and Tower of London test . Subjective measures of sleepiness were recorded both at the beginning and the end of the protocol.

## Data analysis

We used R (R Core Team, 2022) for all our analyses using packages including psych (Revelle, 2021), tabledown (Siraji, 2022), and WRS2 (Mair and Wilcox, 2020). Classical ANOVA methods assume normality and homoscedasticity, and any violation of these assumptions raises serious practical concerns. Hence, we used 10% trimmed mean based robust one-way and/or factorial ANOVA, which were less prone to these assumption violations and outliers (Mair and Wilcox, 2020). “t1way” and “bwtrim” functions from the package “WRS2” (Mair and Wilcox, 2020) were used to conduct the robust oneway and factorial ANOVA respectively. We reported as the explanatory measure of the effect size where 0.10, 0.30, and 0.50 correspond to small, medium and large effect sizes. The confidence interval of the effect size was estimated using 1000 bootstrap samples (Wilcox and Tian, 2011). In the case of significant *F* statistics, we conducted robust pairwise post-hoc tests to compare the three light conditions using the “lincon” function with Bonferroni correction from the WRS2 package.

# Results

## Alerting effects

We observed a significant difference in subjective sleepiness across the three light settings [*F(2,11.7)=*4.85, *p*=0.03, = 0.69 (CI: 0.42-1.04)]. Post-hoc tests revealed that there was a trend of reporting decreased subjective sleepiness (beginning of the protocol vs end of the protocol) in High conditions compared to Low ( =–1.71; *p*=0.09) and Neutral ( = –1.86; *p*=0.07) light conditions. No significant difference between the Low and neutral light conditions was observed (p=1.0).

In aPVT, we did not observe any significant effect of light conditions on general reaction time [*F(2,10.1)=*1.29, *p*=0.32, = 0.54 (CI: 0.21-1.03)], attention lapses [*F(2,10.99)*=0.49, *p*=0.63, = 0.34 (CI: 0.07-0.73)], and 10% fastest reaction time [F*(2,12.21)*=0.09, *p*=0.91, = 0.29 (CI: 0.06-0.66) ]

Bar chart

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*Figure* *1.*  Panel A-D depicts the one-way ANOVA results comparing the light conditions’ effect on (A) subjective sleepiness, (B) general reaction time, (C) attention lapses and (D) 10% fastest reaction time. Each bar represents the mean ± standard error of measurements.

**Working Memory and Executive Functioning**

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We observed a significant difference in forward digit span across the three light settings [*F(2,12.14)*=4.99, *p*=0.03, = 0.59 (CI: 0.34-0.82)]. Post-hoc tests revealed that participants performed significantly better in Neutral conditions compared to Low light condition (=-1.57, *p*=0.04). No other pair-wise comparison in the forward digit span was significant. We did not observe any significant differences in backward [*F*(2,12.11)=0.33, *p*=0.72, = 0.37 (CI: 0.07-0.88)] and sequential digit span task performance [*F*(2,12.05)=0.54, *p*=0.60, = 0.41 (CI: 0.1-0.74)].

In the ToL task we observed a significant effect of light condition on execution time [*F(2,11.47)*=4.38, *p*=0.04, = 0.59 (CI: 0.31-0.85)]. Participants under the Low light condition had significantly lower efficiency than participants under the neutral light condition (=-10.89, *p*=0.04). We did not observe any significant influence of light on efficiency [*F*(2,12.56)=0.11, *p*=0.90, = 0.31 (CI: 0.06-0.68)] and planning time [*F*(2,10.57)=1.20, *p*=0.34, = 0.48 (CI: 0.16-1.04)] in the ToL task.

In the N-back task, we observed a significant main effect of task difficulty where participants had significantly faster reaction time [*F*(1,11.76)=45.71, *p*<0.001, = 0.88 (CI: 0.78-0.98)] and higher accuracy [*F*(1,6.72)=44.43, *p*<0.001, = 0.94 (CI: 0.75-0.99)] in the easy blocks (one back) compared to difficult blocks (two-blocks). However, we did not observe any significant effect of light condition on reaction time [*F*(2,9.26)=2.90, *p*=0.10, = 0.41 (CI: 0-0.79)], accuracy [*F*(2,6.11)=1.24, *p*=0.35, = 0.14 (CI: 0-0.68)], hit ratio [*F*(2,7.05)=2.82, *p*=0.13, = 0.13 (CI: 0-0.60)], false alarm [*F*(2,5.7)=1.28, *p*=0.35, = 0.24 (CI: 0-0.81)], sensitivity [*F*(2,2.91)=1.22, *p*=0.41, = 0.08 (CI: 0-0.61)], bias [*F*(2,2.67)=3.68, *p*=0.17, = 0.14 (CI: 0-0.68)].

Further, we observed no significant interaction effect of light condition and task complexity on N back reaction time [*F*(2,9.25)=1.46, *p*=0.28, = 0.41 (CI: CI: 0-0.79)] and accuracy [*F*(2,6.11)=0.32, *p*=0.74, = 0.14 (CI: 0-0.68)], hit ratio [*F*(2,7.05)=2.24, *p*=0.18, = 0.03 (CI: 0-0.56)], false alarm [*F*(2,5.7)=1.28, *p*=0.59, = 0.24 (CI: 0-0.78)], sensitivity [*F*(2,2.91)=0.03, *p*=0.97, = 0.08 (CI: 0-0.55)], bias [*F*(2,2.67)=1.41, p=0.38, = 0.71 (CI: 0.18-0.91)].

# Discussion

References

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